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Proceedings of the Second Biennial Southern Silvicultural Research Conference

Atlanta, Georgia
November 4-5, 1982

Edited by
Earle P. Jones, Jr.

sil·vics \'sil-viks\ *n pl but sing in constr* [NL *silva*] : the study of the life history, characteristics, and ecology of forest trees esp. in stands

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sil·vi·cul·ture \'sil-və-,kəl-chər\ *n* [F, fr. L *silva, sylva* forest + *cultura* culture] : a phase of forestry dealing with the development and care of forests — **sil·vi·cul·tur·ist** \,sil-və-'kəlch-(ə-)rəst\ *n*

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86 papers are presented in 13 categories: Site Preparation, Prescribed Fire, Pine Regeneration, Hardwood Regeneration, Thinning, Harvesting, Growth and Yield, Biometry, Pest Management, Nursery Practices, Tree Improvement, Water, and Wildlife.

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March 1983
Southeastern Forest Experiment Station
Asheville, North Carolina

Proceedings

of the

SECOND BIENNIAL SOUTHERN SILVICULTURAL RESEARCH CONFERENCE

Edited by

Earle P. Jones, Jr.

Atlanta, Georgia

November 4-5, 1982

Sponsored by:

Southern Forest Experiment Station

Southeastern Forest Experiment Station

Southern Region of the Association of State College and University Forestry Research Organizations

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PREFACE

As its name implies, the Southern Silviculture Research Conference is a place for research scientists to describe and discuss their work in silviculture. Forest practitioners, however, are always anxious to learn the results of silviculture research. Many field foresters attended the Conference, and many more will see these Proceedings. I hope the form and content of this publication will facilitate such use. The 1982 Conference included many aspects of silviculture research in the South, from site preparation to harvesting and from pest management to wildlife management. Of 112 proposals submitted as abstracts for consideration by the Program Committee, 86 were selected for presentation at the Conference. The criteria for selection included timeliness, appropriateness of subject matter, and importance of the message.

The Conference was organized and conducted by a number of people representing university, industry, and Forest Service research organizations. Conference cochairmen for the 1982 conference were John W. Henley and Gordon D. Lewis, of the Southern and Southeastern Stations, USDA Forest Service. Others who served on the Program Planning Committee were:

Roger P. Belanger, Southeastern Forest Experiment Station,
Athens, Georgia

Charles E. McGee, Southern Forest Experiment Station,
Suwannee, Tennessee

James B. Baker, Southern Forest Experiment Station,
Monticello, Arkansas

Michael S. Golden, Auburn University,
Auburn, Alabama

Andrew W. Ezell, Texas A&M University,
College Station, Texas

0. Michael Beach, Champion International,
Huntsville, Texas

Harold J. Hill, Hammermill Paper Company,
Selma, Alabama

Special thanks are due to the contributors who prepared and presented the research papers, and to the 18 moderators who presided over the topic sessions and maintained a very strict time schedule. Thanks also go to others who submitted abstracts for consideration by the Program Committee, and to those who attended the Conference and participated in the discussions of the presented papers.

Papers are published in this Proceedings as they were submitted by the authors--in camera-ready form. Authors are responsible for the content of their papers. Printing and production were supervised by the Southeastern Forest Experiment Station, USDA Forest Service, Asheville, North Carolina.

EARLE P. JONES, JR.
Program Chairman

CONTENTS

Page

PRESCRIBED FIRE

PINE REGENERATION

Page

Page

BIOMETRY

Page

Page

A SPECTRUM OF SITE PREPARATION ALTERNATIVES IN THE LOWER PIEDMONT OF GEORGIA[1/]

M. Boyd Edwards[2/]

Abstract.--At the Hitchiti Experimental Forest impacts of various site preparation treatments are being observed. A mature, natural stand of loblolly pine and some hardwoods were harvested before the treatments. The treatments include 1) control, 2) chainsaw and plant, 3) shear with KG-blade and drum chop, 4) KG, drum chop, and apply herbicide, 5) KG, windrow, burn windrows and disk, and 6) KG, windrow, burn windrows, disk, fertilize, and apply herbicide. This paper reviews research activities from preharvest to 1-year post-harvest.

INTRODUCTION

The selection of site preparation treatments for replanting after loblolly pine (*Pinus taeda* L.) stands are harvested on Piedmont sites must be based on thorough knowledge of both silviculture and applied ecology. Loblolly pine is a subclimax vegetation type, and some treatment is likely to be needed on many soil types to prevent more tolerant species from dominating stands planted after harvests. The purpose of the study described here is to evaluate the effects of various intensities of site preparation on the survival and growth of loblolly pine in the lower Piedmont Province of Georgia. The original stand was carefully sampled and characterized before timber was harvested.

The study area is in Jones County, Georgia, on the Hitchiti Experimental Forest, 20 miles north of Macon. It is an 84.6-acre tract which supported a mixture of pine and hardwood that regenerated naturally after cotton fields were abandoned in the 1930's. The condition is typical of many forested sites in the lower Piedmont.

1/ Paper presented at Second Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ Research Ecologist, Southeastern Forest Experiment Station, Macon, Georgia.

METHODS

A preharvest inventory was conducted in the fall of 1979. First the entire area was divided into 194 0.4-acre plots by means of a 2-chain x 2-chain grid system. Twenty of these plots were randomly selected as a sample of the mature stand. Thus, slightly more than 10 percent of the study area was sampled. A 0.10-acre circular plot was established at the center of each of the square plots. Each overstory tree was tallied by species, d.b.h., and height, and was marked with a numbered aluminum tag at groundline. The tag allowed for additional data, such as tree age, to be taken for selected pines after harvesting. The understory was evaluated by a general classification system based on an estimate of the percentage of cover in grass, vines, and shrubs on ¼-milacre plots distributed on the 0.4-acre plots.

Biomass data were taken by harvesting all vegetation on the ¼-milacre plots and separating it into grasses, vines, and shrubs. This material was ovendried in the laboratory at 80° C and weighed to the nearest 0.1 gram.

In spring 1980, the entire area was clearcut. Late in the summer after harvest, flora on each of the original study plots was surveyed. A 10-foot-wide transect was made diagonally across each 0.4-acre plot, and the first-growing-season invaders were collected. These specimens were identified and deposited in the herbarium at the Hitchiti Experimental Forest.

Site Preparation Treatments

The site was prepared for planting in fall 1981. The experimental design is five replications of six treatments in randomized blocks. Treatment plots each cover about 2 acres. The treatments, in order of increasing intensity, are:

1. Cut only, no site preparation.--These plots were planted in the same manner as the other treatment plots and will serve as controls for the study.

2. Chainsaw and plant.--All trees l-inch d.b.h. or larger, were cut with a chainsaw after the timber harvest. This treatment required about 8 man-days for 10 acres.

3. Shear and chop.--All standing hardwood trees were sheared with a KG-blade, and the area was single chopped with a drum chopper.

4. Shear, chop, and apply herbicide.--In addition to the shearing and chopping of treatment 3, ½ cc Velpar® Gridball™ pellets with 10 percent active ingredient were applied at a rate of 25 lbs/acre in March 1982.

5. Shear, windrow, burn, and disk.--Residuals were sheared with KG-blade, then the debris was pushed into windrows. The windrows were allowed to dry for 3 weeks and. then burned. The remaining debris and ash were scattered over the plot with a dozer blade, then the plots were disked with an offset harrow.

6. Shear, windrow, burn, disk, fertilize, and apply herbicide.--The plots were sheared, windrowed, burned, and disked as in treatment 5. Fertilizer and herbicide will be applied during the second growing season.

The study area was planted in January 1982 at a spacing of 6 feet x 10 feet. The seedlings were improved loblolly pine seedlings obtained from the Georgia Forestry Commission nursery.

Diameter and height growth will be measured annually on the treatment plots. Trees from 50 randomly selected points within each treatment plot will be observed.

PRELIMINARY RESULTS

The preharvest inventory data were summarized by calculating three quantitative parameters--relative density, relative dominance, and relative frequency for all trees 4.5 inches d.b.h. or larger, where

relative density =

$$\frac{\text{number of individuals of species}}{\text{total number of individuals}} \times 100$$

relative dominance =

$$\frac{\text{dominance of species}}{\text{dominance of all species}} \times 100$$

and, relative frequency =

$$\frac{\text{frequency of a species}}{\text{sum frequency of all species}} \times 100$$

These three values were summed to estimate the importance value.

The analysis of these data (Table 1) indicates that loblolly pine was the dominant overstory species in the stand and that sweetgum (*Liquidambar styraciflua* L.) and dogwood (*Cornus florida* L.) were the major codominants.

A total of 14 species of trees was found in the preharvest stand (Table 2). Among stems 1-inch d.b.h. and larger, d.b.h. averaged 7.50 inches and ranged up to 23 inches; height averaged 45.5 feet and ranged up to 136 feet (Table 2). Among 61 sample loblolly pines from the overstory, the mean age was 45 years and the range was from 30 to 63 years.

Ground layer vegetation before harvest was according to the method of Oosting (1956) to determine the percentage of cover for major types of analyzed vegetation. This analysis indicated that 26.70 percent of the total ground layer was various species of grasses, 10.35 percent was vines, and 14.80 percent was shrubs.

In terms of dry biomass in the ground layer there were 2.79 tons/acre in grass, 2.08 tons/acre in vines, and 4.79 tons/acre in shrubs. The total for the three categories was 9.66 tons/acre, which is a sizeable resource.

The postharvest floristic survey revealed specimens from 23 families, 62 genera, and 89 species. It included 4 families 20 genera, and 33 species ofmonocots--mostly grasses. The most frequent grass species were *Panicum* (8 species), *Aristida* (2 species), *Digitaria* (2 species), *Erianthus* (2 species), and *Paspalum* (2 species). There were 19 families, 42 genera, and 56 species of dicots. The largest families were Asteraceae and Fabaceae. Nomenclature in the list of species follows that of Radford, Ahles, and Bell (1968), when possible.

The frequency of each species is the percentage of the 20 sample plots on which the species occurred. Each species has been placed in a frequency class as follows: 0-20 percent--occasional; 21-40 percent--frequent; 41-60 percent--common; 61-80 percent--abundant; 81-100 percent--very abundant. A checklist is available from the author.

Table 1.--Importance/ values (I.V.) for all stems 4.5 inches d.b.h. or larger in preharvest stand

Species	Relative density	Relative dominance	Relative frequency	Importance value	I.V. rank
Prunus serotina	0.26	0.06	3.23	3.55	8
Nyssa sylvatica	0.60	0.19	3.23	4.02	6
Cornus florida	9.28	0.61	20.43	30.32	3
Ulmus alata	1.89	0.23	9.68	11.80	5
Quercus sp.	7.39	2.49	13.98	23.86	4
Diospyros virginiana	0.60	0.03	3.23	3.86	7
Pinus taeda	51.29	90.03	21.51	162.83	1
Juniperus virginiana	0.17	0.12	1.08	1.37	10
Liquidambar styraciflua	28.35	5.65	21.51	55.51	2
Liriodendron tulipifera	0.17	0.30	2.15	2.62	9

Table 2.--Numbers and sizes of individual trees 1-inch d.b.h. or greater in preharvest stand

Species	Number individuals	Mean d.b.h.	Mean ht.	Minimum d.b.h.	Minimum ht.	Maximum d.b.h.	Maximum ht.
		In.	Ft.	In.	Ft.	In.	Ft.
Prunus serotina	3	3.50	16.34	3.00	15.00	5.00	19.00
Nyssa sylvatica	5	4.20	30.18	3.00	22.00	8.00	49.00
Cornus florida	22	3.41	22.83	2.00	10.00	6.00	35.00
Ulmus alata	15	3.23	23.59	1.00	4.00	6.00	43.00
Crataegus sp.	4	2.50	14.76	1.00	6.00	4.00	27.00
Carya .	6	2.75	24.41	2.00	21.00	4.00	35.00
Ilex opaca	1	3.50	14.99	3.50	15.00	3.50	15.00
Acer sp.	9	2.28	21.56	1.00	11.00	4.00	36.00
Quercus sp.	22	9.47	41.54	2.00	4.00	23.00	71.00
Diospyros virginiana	1	3.00	21.00	3.00	21.00	3.00	21.00
Pinus taeda	280	9.47	54.13	2.00	15.00	23.00	136.00
Juniperus virginiana	3	5.17	31.00	2.00	20.00	7.00	43.00
Liquidambar styraciflua	79	4.78	35.73	1.00	10.00	15.00	87.00
Liriodendron tulipifera	4	5.00	42.49	2.00	36.00	7.00	53.00
ALL	454	7.50	45.47	1.00	4.00	23.00	136.00

According to Raunkier's 'law of frequency" (Oosting 1956), the percentage of species expected in the classes should be approximately O>F>C = A<V.[4/] This high percentage of species in the 0-20 percent class and their absence in the 81-100 percent class suggests that the majority of first-growing-season invaders are either low in density or not evenly dispersed. The distribution is also indicative of a diverse flora and the existence of complex micro- and macro-environments.

Soil

An evaluation was made of the effects of the various intensities of site preparation on the chemical and physical properties of the soil, with the help of Dr. Jim Miller of the Southern Forest Experiment Station.

Composite samples were collected with a Lord-tube sampler at each of two depths (0-6 inches and 6-18 inches) at 25-foot intervals along the diagonal transect on each plot. A core sample was also extracted at a depth of 2¼ inches with an impact sampler at every 5th sample point on each transect. Approximately 3 miles of transect were established through the study area for sampling the soil. Samples were taken in 1981 prior to site preparation treatments, and again in the spring of 1982 after treatments.

The soils on the study site are eroded; the A-horizon is partially or wholly missing due to cultivation that ceased approximately 60 years ago. An area adjacent to the study plots is eroded to the C-horizon with gullies over 10 feet deep. The soils on the study site are classified as Ultisols and may be defined more precisely as follows:

Series	Family	Subgroup
a. Cecil	Clayey, kaolinitic, thermic	Typic Hapludults
1. sandy loam		
2. Sandy clay loam		
b. Davidson	Clayey, kaolinitic, thermic	Rhodic Paleudults
c. Vance	Clayey, mixed, thermic	Typic Hapludults

4/ Class 0 will normally be very high because of the numerous sporadic species to be found with low frequency in most stands. Class V, and to a lesser extent A, must always be relatively high because of the species that dominate the community. If quadrants are enlarged, classes 0 and V will enlarge and the lesser classes will decrease accordingly. Frequency, classes, therefore, are comparable only when based upon samples of the same size.

Series appear to change with the aspects of three ridges that are oriented in a southeast direction off a main ridge to the northwest. Intermittent streams with broad, flat sides separate the ridges, and a perennial stream bounds the site to the south and east.

Composite samples will be air-dried and ground to pass a 2 mm sieve. Duplicate 5 g sub-samples will be extracted in 1 N NH_4OAC with 10-minute shaking time to determine extractable calcium, magnesium, and potassium. Manganese will be extracted with 1 N NH_4OAC and intermittent shaking for 6 hours. After filtration, cations will be quantified by standard atomic absorption techniques.

Total nitrogen and phosphorus will be determined in duplicate 1-9 subsamples after wet digestion with sulfuric acid at 310° C. Nitrogen will be quantified with an smmonia-specific ion electrode and phosphorus by the molybdenum blue method.

Core samples will be placed in pressure extractors at 1/3 and 15 atmospheres tension and then ovendried to determine available moisture and bulk density.

The soil samples have been collected and shipped to the Auburn laboratory for analysis. Results of these data will be presented at a later date.

SUMMARY

The original stand condition, including understory vegetation and soils, has been documented. The merchantable trees have been clearcut, six levels of site preparation have been installed, and all plots have been planted with genetically improved loblolly pines at a 6- x 10-foot spacing. Performance of the planted trees and the occurrence of growth of competing vegetation will be monitored through the pine rotation. Ecological data related to succession, competition, and edaphic state will be utilized in determining stand response to the specific treatments.

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1956. The study of plant communities. W. H. Freeman and Co., San Francisco. 440 p.

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1968. Manual of the vascular flora of the Carolinas. Univ. of North Carolina Press, Chapel Hill. 1183 p.

FIRST-YEAR SURVIVAL AND GROWTH OF LOBLOLLY PINE (PINUS TAEDA L.) AS AFFECTED BY SITE PREPARATION ON THE SOUTH CAROLINA AND GEORGIA PIEDMONT[1/]

D. O. Lantagne and J. A. Burger[2/]

Abstract.--Studies were installed on 12 study sites, on the South Carolina and Georgia Piedmont, to determine the effects of several site preparation methods on loblolly pine survival and growth. Among the seven treatments, the shear-pile-disk, shear-disk, shear-V-blade-disc, and chop-burn treatments significantly improved loblolly pine survival and growth by 26 and 50 percent respectively compared to that of the chemical and control treatments. The beneficial effect on survival end growth by tillage treatments was equalled by the chop-burn treatment. Subsoiling improved survival and growth 32 and 30 percent, respectively, over that of the control while discing improved survival and growth 22 and 30 percent, respectively. Results show that good survival and early growth is dependent upon intensive site preparation on the Piedmont. These first-year results and inferences are tentative pending future measurements and evaluations.

INTRODUCTION

Regeneration of intensively managed southern pine forests is accomplished primarily through clear felling, site preparation and planting (McClurkin and Moehring, 1978); however in achieving this goal, considerable variation in approach exists. Timber merchantability standards affect the amount of material remaining after harvest, which in turn affects the choice of site preparation technique, job quality and cost. Site preparation can be accomplished with chemical, fire or mechanical methods and is commonly defined as a set of procedures which provides conditions favorable to seedling survival and growth (Post, 1974). The techniques most commonly employed are shearing, piling, discing, bedding, chopping, herbiciding, burning and subsoiling. Several authors (Brown, 1971; Burns and Reynolds, 1972; Packer, 1972; White et al., 1976; Schultz, 1976) have listed reasons for mechanical site preparation; some of which are applicable to chemical and fire site preparation as well. The reasons include 1) optimizing the soil moisture regime; 2) organic matter incorporation to increase mineralization and nutrient release to promote early growth; 3) reduce vegetation competing for soil moisture and nutrients; 4) clearing the land making planting easier; 5) increase wood production due to both increased survival and seedling growth; 6) shorten the length of the rotation to optimize the financial return; and 7) allow use of genetically improved planting stock.

Although most of the aforementioned site preparation techniques are used in the Piedmont, there presently exists little documentation of their effect on survival and growth. studies on the effect of various site preparation techniques on loblolly pine survival and growth have been carried out by forest, industries on the Piedmont but the results have not been widely disseminated. Haines (1978) studied the effect of several site preparation techniques on loblolly pine survival and growth. One of several treatments was aiscing, and when compared to the control, the results indicated no significant increases in survival, height and seedling volumes after two growing seasons.

1/ Research funded and established in cooperation with the Western Carolina Region of Champion International Corporation. Paper presented at the Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ Graduate Assistant and Assistant Professor of Forest Soils respectively, at Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

The effects of subsoiling on survival and growth of horticultural and forest tree species on the Piedmont have been evaluated. Savage et al. (1968) reported that subsoiling prior to planting of peach trees affected survival and growth when measured 3 and 13 years after establishment. At 3 years, height growth of seedlings in the uneubsoiled treatments was 50 percent less than seedlings in the subsoiled treatments. Seedling volumes were also substantially improved. After 13 years, survival and seedling volume were approximately 25 percent better in the subsoiled treatments. Berry **(1979)**, working in the Piedmont of Georgia, found that subsoiling increased height and root-collar diameter of five year old loblolly (*Pinus taeda*) and shortleaf pines (*Pinus enchinata*) **by 5 and** 10 percent, respectively. The resulting increase in seedling volume of 19 percent was a significant improvement. Berry concluded that subsoiling would be beneficial on many sites of this type.

The objective of this research was to quantify the effect of several site preparation prescriptions on first-year survival and growth of loblolly pine.

PROCEDURES

Study Sites

Three study areas in the central Piedmont, two in western South Carolina and one in eastern Georgia, were selected. The South Carolina areas were located in Fairfield and **Newberry** counties, and the Georgia areas in the counties of Wilkes and Oglethorpe (fig. 1). Four sites supporting natural, mature loblolly pine-hardwood stands, were selected within each area and **clearcut** in the **summer** of 1980. The prevalent hardwoods on the sites were yellow-poplar (*Llriodendron* ***tulipifera***), post oak (*Quercus stellata*), white oak (*Quercus* ***alba***), water oak (*Quercus* ***nigra***), and willow oak (*Quercus phellos*) . Eastern red cedar (*Juniperus* ***virginiana***) was often an understory component. The **clearcut** stands ranged in age from 30 to 50 years, **with** site indices (base age 50) ranging from 68 to 90.

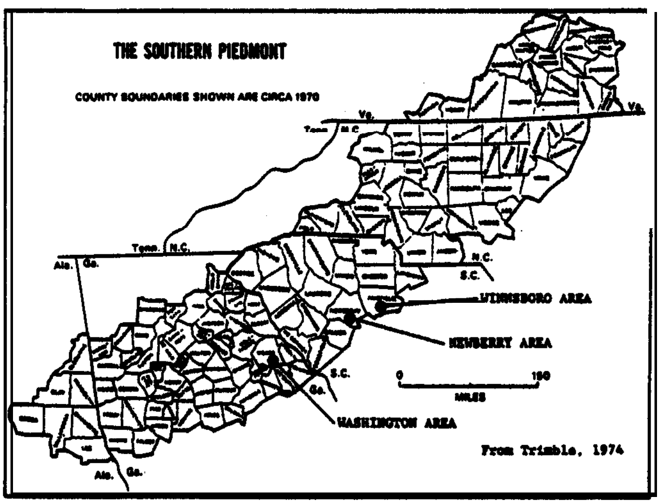

Figure 1.**--Map** of the Southern Piedmont showing the location of the study sites.

In addition to forest cover, sites were selected on the basis of similarity in soil type. The soils of the study sites were Appling, Pacolet, Cecil or Hiwasee which have minor differences in the depth, color and texture of the subsoil (SCS, 1975). The **soils** are deep, well drained with medium fertility and moderate permeability. All are clayey, **kaolinitic, thermic,** Typic Hapludults except **Hiwasee** which **is** a **Typic Rhodudult.** The uneroded surface soils are predominantly sandy loam and the subsoils range from a sandy clay to clay. Bulk density of the surface **soils** ranged from 1.17 to 1.24 **gms/cm^3** prior to disturbance.

Site Prescriptions

A spectrum of operationally feasible prescriptions, varying In intensity and cost, were Included in the study. The seven treatments ranged from a control to a f-pass prescription. They Included:

1. Control
2. Herbicide and bum
3. Chop and bum
4. Shear, rake-pile
5. Shear and disc (l-pass)
6. Shear, V-blade and disc **(2-pass)**
7. Shear, rake-pile, disc **(3-pass)**

Figure 2 shows an idealized layout of the study. Treatments within study sites ranged in **size** from three to five acres. All treatments were applied in the **summer** and fall of 1980. Glyphosate was aerially applied at a rate of 1 gallon **Roundup**[R] per acre. After **six** weeks the treated areas were burned.

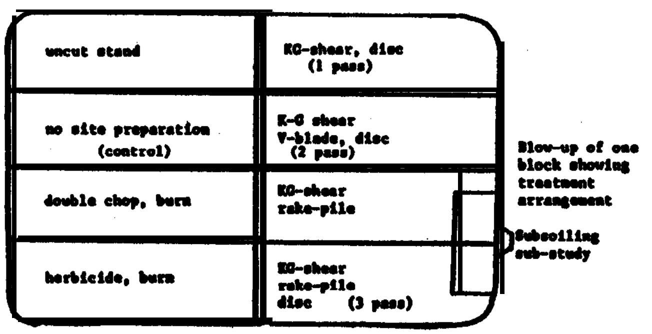

Figure **2.--** Idealized experimental layout of the site preparation treatments and'controls.

The shear and disc prescription (5) was applied **with** shearing and **discing** occurring simultaneously.

Residual vegetation was sheared in place; however some piling occurred when vegetation and debris was exceptionally heavy. The shear, V-blade and disc treatment (6) consisted of shearing residual vegetation in place with the first pass, followed by a V-blade and disk with the second pass. The V-blade aligned the sheared material into small windows between which the soil was disced. The remaining site preparation prescriptions are self-explanatory. All treatment areas were planted by machine, with 1-0 genetically improved loblolly pine, with the exception of the control and herbicide plots which were hand planted. Five 0.1 acre subplots were randomly located within each treatment plot. Each subplot contained approximately 64 seedlings which provided about 320 measured trees per treatment.

Subsoiling Study

The subsoiled plots, located only in the Georgia area, have a 2 x 2 factoral arrangement of treatments in a split-plot design (fig, 3). Each of the four replicates is 0.8 acre in size and contains the following four 0.2 acre treatments:

1. Control
2. Subsoil (single 24 in (60 cm) long tooth)
3. Disc (tandom harrow with 35 inch (90 cm) diameter discs)
4. Disc and subsoil

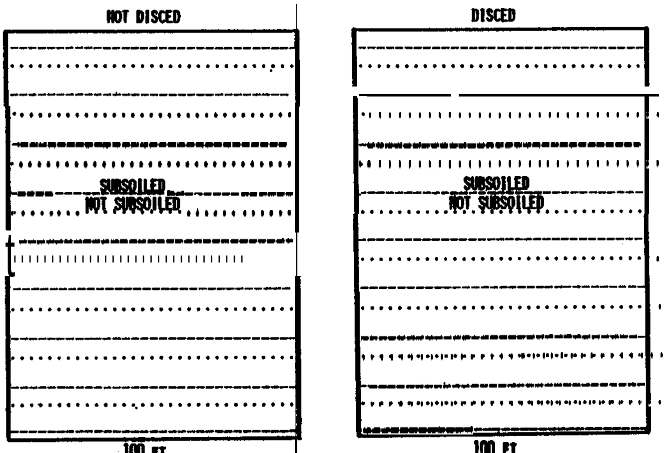

Figure 3.--Experimental layout of the subsoiling study.

Subsoil furrows (split-plot) were made across the disced and non-disced main plots. The sites were machine planted with 1-O genetically improved loblolly pine seedlings, within and between furrows, for a total of 18 rows at a final seedling spacing of 8 x 8 feet. All planting was accomplished in late March 1981.

Approximately 100 trees were measured for each treatment at each site. Survival, tree height, and root-collar diameter were recorded in early March 1982. Data within each area was analyzed separately using analysis of variance procedures (Sokal and Rohlf, 1969). This paper reports on these first-year results.

RESULTS

Site Preparation Prescriptions

Seedling survival in the five mechanical treatment plots was significantly better than seedling survival in the herbicide-burn and control plots (Table 1). Survival was 30 percent better in the shear-pile and shear-pile-disc plots, and 22 percent better in the shear-pile and chop-burn plots as compared to the herbicide-burn and control plots. The differences among mechanical treatments were not significant with the exception of the shear-pile-disc which had significantly better survival than the chop-burn treatment.

The mechanical treatments, with the exception of the shear-pile prescription, improved height growth by a significant 11 percent over that of the herbicide-burn and control treatments (Table 1). The shear-pile-disc had significantly greater height growth than the chop-burn treatment, but was not significantly different from the other mechanical treatments, again with the exception of the shear-pile treatment.

Except for the shear-pile treatment, seedling volumes (D^2H volume index) were significantly improved by mechanical prescriptions (Table 1). The shear-v-blade-disc and shear-pile-disc prescriptions improved volume about 60 percent over that of the herbicide-burn and control treatments and 40 percent over the shear-pile prescription. The shear-disc and chop-burn treatments improved volume nearly 50 percent over the herbicide-burn and control treatments, and a nonsignificant 25 percent over the shear-pile treatment.

Subsoiling Study

Subsoiling and discing significantly increased seedling survival by 22 and 12 percent, respectively, and seedling volume by 13 percent for both treatment s (Table 2). The disc x subsoil interaction was also significant for survival and seedling volume meaning there was an additive effect for these two treatments.

An analysis of the significant interaction term for survival showed that subsoiling improved survival by 12 percent over discing alone, and by 32 percent over the control, while discing alone improved survival by 22 percent over the control (fig. 4). An analysis of the significant disk x subsoil volume interaction showed a significant 30 percent increase over the control by both treatments (fig. 5).

Table 1.--Loblolly pine survival and growth as affected by site preparation treatments.

Site Preparation Treatments	Survival	Height	Diameter	Volume Index[1/]
	(%)	(cm)	(mm)	(cm^3)
Control	45a[3/]	27.5a	5a	9a
Herbicide[2/] and Burn	47a	28.3a	5a	11ab
Chop and Burn	58b	30.6b	6ab	20cd
Shear, Rake-Pile	59bc	28.7a	6ab	15bc
Shear and Disc (1-pass)	65bc	30.9b	7b	20cd
Shear, V-Blade and Disc (2-pass)	59bc	30.9b	7b	26e
Shear, Rake-Pile, Disc (3-pass)	67c	32.5b	7b	24de

1/ Volume Index = d^2 x ht

2/ Glyphosate as Round-up[R] applied by helicopter in September.

3/ Means with different subscripts are significantly different at the .05 level of probability using Duncan's Multiple Range Test.

DISCUSSION

During site preparation and planting, and for some months following, the southeastern United States experienced drought conditions. In the period from June 1980 to June 1981, actual rainfall averaged 13 inches below normal. six tenths of an inch was received 27 days prior to planting on the Georgia sites, however in the 15 days after planting 2.5 inches of rainfall was received in two events. Only 1.25 inches of rain was received on the South Carolina sites over a 44-day period prior to planting. While the seedlings were planted over a period of several days during which 1.3 inches of rain was received, there were only 0.8 inches of rain over the next 28 days. The lack of rainfall during this critical period of seedling establishment is largely responsible for the overall poor seedling survival on these sites.

The site preparation prescriptions used in this study vary in cost, competition control, degree of tillage, and the extent to which organic materials were manipulated. Shearing, chopping and herbicides reduce the amount of residual material which could compete with seedlings for light, moisture and nutrients. After shearing, material is raked into piles which allows for effective discing and easy planting. Chopped and

Table 2.--Loblolly pine survival and growth as affected by subsoiling and discing.

Site Preparation Treatments	Survival	Height	Diameter	Volume Index[2/]
	(%)	(cm)	(mm)	(cm^3)
Control	72a[1/]	31.6a	7a	20a
Disc	82b	31.7a	7a	23b
Control	68a	30.9a	7a	20a
Subsoil	87b	32.3a	7a	23b

1/ Means with different subscripts are significantly different at the .05 level of probability using Duncan's Multiple Range test.

2/ Volume Index = d^2 x ht.

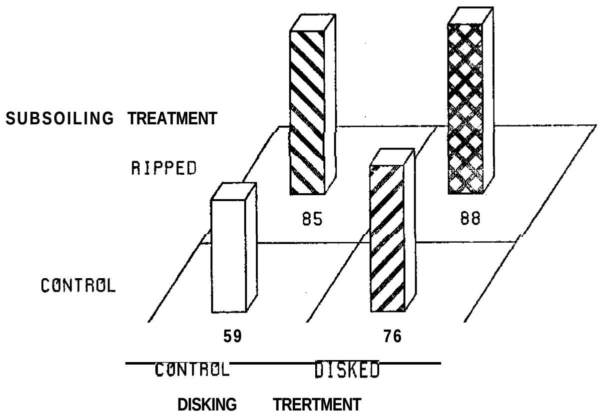

Figure 4.--Interaction effect of discing and subsoiling on loblolly pine survival (percent).

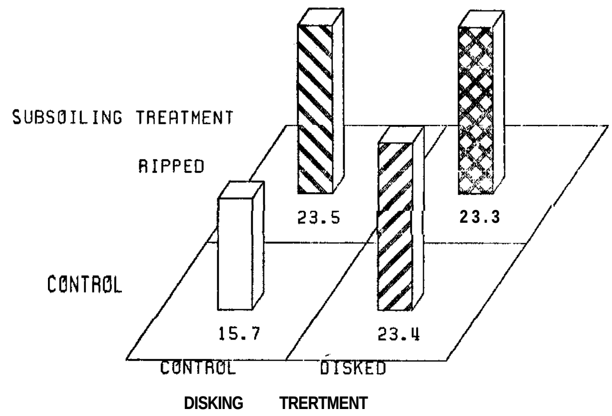

Figure 5.--Interaction effect of discing and subsoiling on loblolly pine seedling volume (cm^3).

herbicided areas are normally burned to reduce the amount of residual material at ground level and to control sprouting hardwoods. Burning the treated area provides readily available nutrients for seedlings and leaves the larger materials to decompose and slowly release nutrients over the long term. Discing, the final step in the **shear-**rake-disc treatment is often thought to be necessary for the enhancement of survival and growth. The disc does provide competition control through soil **tillage,** and with the incorporation of organic matter, increases short-term mineralization and available nutrients.

The shear-v-blade-disc treatment left the organic materials on the site by eliminating the rake but retained the beneficial effects of soil **tillage.** The shear-disk operation reduced the necessary passes for site preparation to one and provides both the benefits of discing and larger long term nutrient pools.

With each reduction in the number of passes the disk was less effective in tilling the soil surface, however the shear-rake-disc prescription did not result in better survival or growth when compared to the other prescriptions using the disc. Seedlings in the chop-burn treatment did equally as well in survival and growth as those in the shear-disc and shear-v-blade-disc plots. Discing in the 3-pass prescription did not enhance the seedling volume growth over that achieved by the chop-burn treatment and in general has not provided a significant reason for its use to date. The herbicide-burn treatment did poorly which is thought to be due in part to a higher level of vegetative competition.

While subsoiling did improve survival and growth, it should be noted that dry soil conditions allow for effective breakage of compact subsoils and that soil conditions at the time of study establishment were probably drier than could be expected in a year of normal rainfall. The effect of the disc + subsoil combination on seedling survival and growth was neither additive nor synergistic and appears to be an expensive alternative to discing or subsoiling only. Although subsoiling alone improved seedling survival compared to discing, it did not improve seedling volume over that of discing and is an expensive alternative to discing alone. As seedlings grow, the loosened subsoil may provide a greater effective soil volume for rooting and provide benefits not yet discernible within the first growing season. Overall this study showed that improved survival and growth was dependent upon some type of intensive site preparation.

CONCLUSIONS

First-year results show the beneficial effect of mechanical site preparation on early seedling survival and growth. The chop-burn treatment was as effective as the shear-disc, and **shear-V-blade-**disc treatments for improving seedling survival and height growth and was not significantly different from the shear-rake-disc treatment in volume growth. Subsoiling significantly improved seedling survival over that of discing and the control, but the disc + subsoil combination did not significantly improve seedling survival over that of subsoiling alone. Subsoiling does not significantly improve seedling growth over that achieved by discing and appears an expensive alternative to discing in either case. These are first-year results and inferences made are only tentative pending future measurement and evaluation.

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MECHANICAL SITE PREPARATION IMPROVES GROWTH OF GENETICALLY IMPROVED AND UNIMPROVED SLASH PINE ON A FLORIDA FLATWOODS SITE 1/

Kenneth W. Outcalt 2/

Abstract.-- In 1971 genetically improved and unimproved slash pine *(Pinus elliottii* Engelm.) seedlings were planted on north Florida flatwoods sites prepared by four different methods: no treatment (control), prescribed burn, burn + double disk, and burn + double disk + bed. Ten years after planting, survival of seedlings established under all treatment conditions was equally good, averaging almost 90 percent. There were no differences in diameter, height, or volume between control and burn-only plots. Disking significantly increased average tree diameter and height. Volume production was 60 percent greater on the disked than on control or burn plots. Bedding after disking was no better than disking alone. Genetically improved stocks yielded about 40 percent more wood than unimproved stock at age 10.

Intensive site preparation has become a standard practice for establishment of pine plantations on most sites in the Atlantic and Gulf Coastal Plains. Past work has shown that mechanical site preparation, such as disking and/or bedding, can increase initial survival and growth of planted pines (Derr and Mann 1970, Lennartz and McMinn 1973). The relative effectiveness of various methods, however, depends on site characteristics (Derr and Mann 1977). The study described here was established to compare the effects of different site preparation methods on survival and growth of slash pine on a north Florida flatwoods site. A secondary purpose of the study was to compare the response of genetically improved with unimproved slash pine seedlings when planted on areas prepared by different methods. Reported here are the results at plantation age 10 years.

METHODS

The study area of about 8 acres is on the Olustee Experimental Forest in Baker County, Florida. The soil is a poorly drained Leon fine sand (Aeric Haplaquod) with a spodic horizon at a depth of 12 to 18 inches. The water table is at or near the surface during portions of the year (Schultz 1976) and mottling occurs in the profile at 15 to 21 inches.

Twenty-four plots, each 70 by 100 feet, were established in a randomized block design with 3 blocks, 4 methods of site preparation, and 2 types of planting stock. The site preparations were: no treatment; prescribed burn; burn and double disk; and bum, double disk, and bed. Planting stock was of two types: unimproved and genetically improved, a mixture of 10 superior families. Types of stock were included in factorial combinations with the different methods of site preparation.

In 1968 a sparse stand of 60-year-old longleaf pine *(Pinus palustris* Mill.) was harvested from the site. Sites were prepared in the spring of 1970. The prescribed burns (backfires) consumed most of the vegetation, leaving only woody stems of shrubs standing. A heavy-duty offset harrow was used for disking. Beds about 6 inches high and 10 feet apart were formed with a bedding harrow and water-filled rolling hourglass packer.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Improved seed was collected from select *crosses* in the Olustee Experimental Forest clone bank. The Florida Division of Forestry furnished unimproved seed and grew all the seedlings at its Chiefland nursery. In February 1971, 1-0 seedlings were lifted and planted on the study site. One hundred trees were hand-planted in each of the 24 plots. Spacing was 7 feet within rows with rows 10 feet apart. A 4-row isolation strip planted to unimproved seedlings was established around each plot.

RESULTS

Site preparation had no significant effect on survival, with all treatments having good survival at 10 years of age (table 1). Burning improved neither survival nor growth of trees. Mechanical site preparation, however, increased growth of both improved and unimproved stock. Disking increased average tree diameter by 0.5 inches, average height by 3.8 feet, and volume production by over 200 feet^3/acre (0.25 cds/acre/year) above control trees. Trees on disked and bedded plots were not significantly larger than those on disked-only plots.

Table 1.-Survival. growth, and yield of slash pine, by type of seedling and method of site preparation 10 years after planting.

Seedling type and site preparation	Survival	Average diameter	Average height	Volume 1/
	(percent)	(inches)	(feet)	(ft^3/acre)
Unimproved seedlings				
Control	a3	3.3	20.4	280
Burn	a7	3.0	18.4	240
Burn + disk	91	3.6	22.6	405
Burn + disk + bed	90	4.1	25.6	575
Average	88	3.5	21.8	375
Improved seedlings				
Control	a2	3.5	22.4	345
Burn	a3	3.5	22.3	360
Burn + disk	91	4.3	21.7	680
Burn + disk + bed	90	4.4	28.3	705
Average	87	3.9	25.2	523
All seedlings				
Control	a3 a 2/	3.4 a	21.4 a	315 a
Burn	aS a	3.3 a	20.3 a	300 a
Burn + disk	91 a	3.9 a	25.2 b	545 b
Bum + disk + bed	90 a	4.2 b	27.0 b	640 b

1/Total Inside bark volumes based on equation of Schmitt and Bower (1970).

/Values within a column not followed by the same letter are significantly different at the .05 level.

Improved and unimproved seedlings had equally good survival at age 10, but improved trees grew faster than unimproved ones. After 10 growing seasons improved trees were an average of 0.44 inches larger in diameter and 3.4 feet taller and had produced 40 percent more wood. The overall interaction between site preparation and planting stock was not statistically significant, but it appears that bedding after disking was beneficial for growth of the unimproved, but not the improved seedlings.

DISCUSSION

The similarity in growth between trees on the control and the burned plots was due, at least in part, to the l-year delay between site preparation and planting. A contributing factor was the greater amount of understory vegetation, especially saw palmetto (*Serenoa repens* [Bartr.] Small) on burn plots prior to treatment (Schultz 1976). Although the burn reduced competition, by planting time the burned plots had as much or more competition than the control plots.

A major justification for bedding flatwoods sites is to increase seedling survival by reducing prolonged saturation of the root zone (Schultz 1976). However, not all sites are wet enough to benefit from this treatment. On some sites disking is as effective as bedding for increasing growth of planted slash pine (Derr and Mann 1977, Cain 1978). The reason for the lack of response on some sites may not be completely understood, but what sites it will occur on has become more predictable. Bedding sites with Spodosols without an argillic horizon, like the.soil in this study, has not improved site productivity (Broerman and Sarigumba 1981). On these soils competition control is the major benefit of site preparation, and disking or harrowing accomplishes this quite well. Bedding after disking on these soils will not-likely pay off and can even cause some negative effects. Thus, bedding like most silvicultural practices needs to be prescribed by site.

Since there was no interaction between site preparation and type of planting stock, their effects are assumed to be additive. Disking should increase volume production at age 10 by about 230 cubic feet per acre over untreated sites no matter what type of planting stock-is used. The gain from using the improved stock should be about 150 cubic feet per acre. With improved stock planted on disked sites, volume at age 10 should average about 660 cubic feet per acre, or about double the yield from untreated sites planted with unimproved stock.

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RESPONSE OF PLANTED PINES TO SITE PREPARATION ON A BEAUREGARD-CADDO SOIL[1/]

James D. Haywood[2/]

Abstract .-The only real advantage to mechanically preparing sites prior to planting was better survival of loblolly pines at age 2. Slash pine survival was unaffected by site treatment. Because of survival differences, more volume (535 ft^3 (o.b.)/A) was thinned from 13-year-old loblolly stands that had been mechanically treated than from burned-only stands. After the first thinning, the method of site preparation did not influence the growth rate of either pine.

INTRODUCTION

Pine survival on somewhat poorly to poorly drained silt loam flatwoods in Louisiana is usually acceptable without site preparation. Yet, the inherent wetness of these sites and competition from dense plant cover slows initial height growth of newly planted pines. To determine if harrowing or bedding would improve survival and increase the rates of height and diameter growth on these flatwoods, studies were initiated by the Southern Forest Experiment Station in Pineville, Louisiana. This paper summarizes data through age 20 on survival and yield of planted loblolly (*Pinus taeda* L.) and slash (*P. elliottii* Engelm. var. *elliottii*) pines from one of these studies.

SITE DESCRIPTION

The study area, located in Rapides Parish, Louisiana, comprises Beauregard (Pinthaquic Paleudult, fine-silty, siliceous, thermic), and Caddo (Typic Glossaqualfs, fine-silty, siliceous, thermic) silt loam soils. These soils are acidic, have low natural fertility, and are common in flatwoods of the West Gulf Coastal Plain. Relief is level to slightly sloping, but a few "pimple" mounds are present. The Caddo soil has very slow surface and Internal drainage; the Beauregard has medium drainage throughout. These soils have a perched water table which can be at or just below the surface during extended periods from December through February. On any given date, depth to this water table was highly variable from one replicate to the next.

Originally, the site supported a longleaf pine (*P. palustris* Mill.) stand. After harvesting, a cover of bluestem (*Andropogon* spp.) and scattered post oak (*Quercus stellata* Wangenh.), blackjack oak (Q. *marilandica* Muenchh.), and southern bayberry (*Myrica cerifera* L.) developed. Prior to initiation of site preparation treatments, the area was burned to reduce the grass rough and the woody vegetation cut down and removed.

METHODS

Treatments were replicated three times with each species in a randomized block design. Site treatments were:

Burn-only--The study plots were burned to facilitate planting.

Burn-harrow--Plots were treated with an offset disk harrow in the fall of 1960 and again in July 1961 to eliminate grass competition.

Burn-harrow-bed--After harrowing, the plots were double bedded by making two passes with a bedding harrow. Beds were spaced 8 feet apart and averaged 20 inches tall from furrow-to-crest before settling. By age 15, the beds averaged 10 inches tall.

Harrowing was done twice, because after the fall 1960 harrowing treatment heavy rains kept the bedding treatment from being applied. By the next spring, grasses had reinvaded the harrowed plots, which necessitated a second harrowing treatment in July 1961. The burn-harrow-bed plots were bedded in late September 1961.

[1/] Paper presented at the Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Graded, bare-root, 1-0 loblolly and slash pine seedlings were planted by hand at a 6- by 8-foot spacing on 0.36 acre plots during February 1962. Heights and diameters at 4.5 feet above groundline (d.b.h.) were taken on the center 100 trees per plot over several years. The plots were thinned after the 13th growing season. Leave-trees were selected by the following criteria: (1) absence of fusiform rust galls on the main stem, (2) stem quality, (3) spacing, and (4) tree size. No truck or heavy equipment traffic was allowed within the plots, and the residual stand was undamaged by the thinning operation.

Volumes harvested at age 13 were estimated by use of a local volume table developed for each plot (Spurr 1954). At ages 15 and 20, total stem wood volume outside bark (o.b.) was calculated for standing loblolly (Hasness and Lenhart 1972) and slash (Moehring _et al._ 1973) pines.

Pine survival, quadratic mean d.b.h., average height, and volumes per acre were analyzed at different ages with analyses of variance ($\alpha=$ 0.05) and preplanned orthogonal trend comparisons (burn-only vs burn-harrow + burn-harrow-bed and burn-harrow vs burn-harrow-bed). The analysis compared species and treatments and determined if species by treatment interactions occurred. Also, treatments among individual species were compared. Percentages were transformed into arcsine $\sqrt{\text{proportion}}$, and both percentages and transformed data were analyzed.

RESULTS

Responses before thinning

There was a species by treatment interaction for average heights of 2-year-old pines (table 1). Loblolly was taller on the burn-harrow plots than on the other two treatments, while slash was tallest on the burn-harrow-bed plots. Slash was taller than loblolly on the burn-only and burn-harrow-bed plots, but the two species had similar average heights on the burn-harrow plots. In the comparisons across both species, loblolly averaged 3 feet taller than slash by age 8, and this height difference persisted through age 13. At age 8, pines on the two mechanical treatments averaged two feet taller than those on the burn-only plots, while pines on the bum-harrow-bed plots were two feet taller than those on the burn-harrow plots. By age 13, pine height differences among treatments were not significantly different.

At 8 years, slash pines on the burn-harrow-bed plots averaged a 0.4-inch greater d.b.h. over those on the other two treatments, but no diameter difference was shown at age 13 (table 1). In the comparisons across both species, loblolly averaged 0.2-inch greater d.b.h. than slash at age 8, and this difference persisted through age 13.

Survival among 2-year-old loblolly pines on the bum-only plots averaged 15-percentage points less than survival among those on the mechanical treatments (table 1). By age 13, differences in survival were not significantly different.

The thinning operation

The thinning operation at age 13 reduced loblolly stocking from 725 to 343 trees per acre, while slash stocking was reduced from 682 to 346 trees per acre (table 2). Among loblolly pines, this reduced the basal area on the bum-only plots by 52 ft^2/acre, while the reduction in basal area averaged 75 ft^2/acre on the two mechanical treatments. Among slash pines, the reduction in basal area varied little and averaged 55 ft^2/acre across all treatments.

Responses after thinning

In the comparisons across both species, loblolly maintained a 3-foot height advantage over slash through age 20 (table 3). At 15 years, pines on mechanically treated plots averaged l-foot taller than those on bum-only plots, but this height difference was no longer significant by age 20. Through age 20, loblolly averaged a 0.3-inch greater d.b.h. than slash. There were no diameter differences among treatments, however.

At age 13, more loblolly volume per acre was cut on the' two mechanical treatments than was cut on the bum-only plots (table 3), but at age 15, loblolly on the bum-only plots produced more standing volume per acre than those on the two mechanical treatments. By age 20, loblolly standing volume per acre was similar among all treatments. However, the difference in harvested volumes at age 13 meant that loblolly on the mechanical treatments averaged 12 percent more total wood production (harvested and standing volumes) per acre over those on the bum-only plots, but this volume difference was not statistically significant. For slash pines, there were no volume differences among treatments.

DISCUSSION

Loblolly pines planted on mechanically treated plots had a higher survival rate at age 2 and a 2-foot height advantage at age 8 over loblolly planted on plots not mechanically treated. This higher survival and improved early height growth on the mechanically treated plots was translated into greater yields at thinning, an added 535 ft3 (o.b.) per acre at age 13. The approximately 6 cord per acre gain in pulpwood volume was worth about $96 at 1982 stumpage prices. After the first thinning, the method of site preparation did not influence the growth rate of the pines. Since treatments were thinned to similar basal areas, volume production at age 20 was also similar **among** treatments. Slash pine survival and yields were not influenced by site treatment.

Survival was similar between species, but loblolly pines outgrew slash pines in both **d.b.h.** and height. These differences did not translate into added gains in volume for loblolly, because at a given **d.b.h.** and height, slash pine has 12 percent more volume per tree than loblolly pine (Hasness and **Lenhart** 1972, **Moehring,** et al. 1973).

In conclusion, the silt loam flatwoods of Louisiana are inherently productive eites. Site preparation beyond the level needed to insure adequate pine stocking will only produce modest gains in pulpwood yields at first thinning.

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Table 1 .--Pine responses to initial site preparation, before thinning

Species and treatments	Survival Age2	Survival Age13	Height Age 2	Height Age 8	Height Age 13	Quadratic mean d.b.h. Age 8	Quadratic mean d.b.h. Age 13
		percent	*feet*	*feet*	*feet*	*inches*	*inches*
Loblolly pine							
Burn-only	74 a 1/	71 2/	2.2 a 3/	26	46	4.3	6.2
Burn-harrow	88 b	82	2.5 b	28	48	4.5	6.1
Burn-harrow-bed	90 b	87	2.1 a	29	48	4.5	6.0
Mean for all three treatments	84	80	2.3	28	47	4.4	6.1
Slash pine							
Burn-only	87	76	2.5 b	24	43	4.1 a 1/	5.9
Burn-harrow	81	73	2.5 b	24	43	4.1 a	5.9
Burn-harrow-bed	89	76	2.8 c	27	45	4.5 b	5.9
Mean for all three treatments	86	75	2.6	25	44	4.2	5.9
COMPARISONS **ACROSS** BOTH SPECIES							
Loblolly pine	84	80	**2.3 4/**	28	**47**	4.4	6.1
Slash pine	86	75	**2.6***	**25***	**44***	4.2"	5.9"
Burn-only	80	**73**	2.4	**25**	45	4.2	6.0
Mechanical	87	**80**	2.5	**27***	46	4.4	6.0
Burn-harrow	85	77	2.5	26	45	4.3	6.0
Burn-harrow-bed	90	82	2.5	**28***	46	4.5	6.0

1/For loblolly or slash pine, columnar **means** followed by the same letter are not significantly different (α = 0,05)
2/For columnar means not followed by any letter, there were no significant differences.
3/At age 2, there was a species by treatment interaction for height of pines. **Columnar** means followed by the **same** letter are not significantly different (a = 0.05)
4/Paired comparisons followed by an asterisk are significantly different (a = 0.05).

Table 2.--Stems per acre and basal area in square feet before and after plots were thinned during the thirteenth growing season

Species and treatment	Trees per acre: Before thinning	Trees per acre: After thinning	Basal area: Before thinning	Basal area: After thinning
	Stems/acre[1]		*ft²/acre*	
Loblolly pine				
Burn-only	646[2]	347	140	88
Bum-harrow	740	340	155	84
Burn-harrow-bed	790	340	160	81
Mean for all three treatments	725	343	152	84
Slash pine				
Bum-only	688	345	134	79
Burn-harrow	665	345	129	77
Burn-harrow-bed	692	347	136	78
Mean for all three treatments	682	346	133	78

1/ Statistical analysis was not done on these data
2/ 908 pines were planted per acre for each treatment.

Table 3.--Pine response to initial site preparation, after thinning

Species and treatment	Height: Age 15	Height: Age 20	Quadratic mean d.b.h.: Age 15	Quadratic mean d.b.h.: Age 20	Total stem volume per acre: Age13 harvested.	Total stem volume per acre: Age 15 standing	Total stem volume per acre: Age 20 standing	Total stem volume per acre: Total production at age 20
		feet	*inches*	*inches*	*ft³ (o.b.)*	*ft³ (o.b.)*	*ft³ (o.b.)*	*ft³ (o.b.)*
Loblolly pine								
Bum-only	51[1]	60	7.5	8.7	1,010 a[2]	2,150 b	3,420	4,430
Burn-harrow	53	62	7.4	8.7	1,450 b	1,970 a	3,460	4,910
Burn-harrow-bed	53	61	7.2	8.4	1,640 b	1,880 a	3,350	4,990
Mean for all three treatments	52	61	7.4	8.6	1,370	2,000	3,410	4,780
Slash pine								
Burn-only	49	58	7.2	8.4	1,110	2,100	3,380	4,490
Bum-harrow	49	57	7.1	8.2	1,040	1,980	3,320	4,360
Bum-harrow-bed	50	60	7.1	8.3	1,240	1,950	3,070	4,310
Mean for all three treatments	49	58	7.1	8.3	1,130	2,010	3,260	4,390
COMPARISONS ACROSS BOTH SPECIES								
Loblolly pine	52[3]*	61*	7.4,	8.6,	1,370	2,000	3,410	4,780
Slash pine	49	58	7.1	8.3	1,130	2,010	3,260	4,390
Bum-only	50*	59	7.3	8.5	1,060	2,130	3,400	4,460
Mechanical	51	60	7.2	8.4	1,340	1,940	3,300	4,640
Bum-harrow	51	60	7.2	8.4	1,250	1,980	3,390	4,640
Bum-harrow-bed	51	60	7.1	8.3	1,440	1,910	3,210	4,650

1/ For columnar means not followed by an letter, there were no significant differences
2/ For loblolly pine, columnar means followed by the same letter are not significantly different (α = 0.05)
3/ Paired comparisons followed by an asterisk are significantly different (a = 0.05)

EFFECT OF SURFACE SOIL REMOVAL ON SELECTED
SOIL PROPERTIES AND LOBLOLLY PINE
SEEDLINGS AFTER THE FIRST GROWING SEASON[1/]

Charles L. Tuttle, Michael S. Golden, and Ralph S. Meldahl[2/]

Abstract -- The effects of removal of 0, 2.54 and 7.62 cm of topsoil were tested on five sites in east-central Alabama. Results of the first year's data showed; 1) an increase in seedling survival on plots where the topsoil was removed; 2) higher bulk density on the treated areas than on the control; and 3) soil nutrient levels were significantly reduced after one growing season. Other variables (height growth, organic matter. etc.) were also tested but did not exhibit significant difference8 after 1 year.

INTRODUCTION

Harvesting and site preparation procedures currently are being used on over 60.000 ha of forest land in Alabama each year (Forest Industries Council 1980). Harvesting and mechanical site preparation many times results in moderate to severe topsoil disturbance, exposure, or removal due to the equipment used and through possible erosion losses (Blackburn et al. 1978; McClurkin and Moehring 1978; Golden et al. 1982). Glass (1976) estimated that at least 5.08 cm of topsoil were removed from a Piedmont site in North Carolina by root-raking alone. Further attempts have been made to quantify the amount of topsoil lost from forest sites by using the Universal Soil Loss Equation and it8 modifications (Wiscbmeier and Smith 1978; Dissmeyer and Foster 1980). However, little quantitative data is available to show the effects of topsoil removal on soil properties and seedling survival and growth.

This paper presents partial first year results of a study designed to quantify the effects of topsoil removal on selected soil properties, seedling survival, and seedling growth. The question8 which we hope to answer include : (1) does the quantity of topsoil lost from a site affect the quantity of nutrient8 in the soil that are available for plant use. (2) is there a change in nutrient levels within treatments over time. and (3) does the quantity of soil lost have an effect on seedling survival and growth?

METHODS AND PROCEDURES

Plot Location and Establishment

Five study sites. two in the Piedmont and three in the Hilly Coastal Plain of Alabama, were selected. At each site. a split plot design containing three replications of three treatments was used. Treatment8 consisted of a control (no topsoil removed), 2.54 cm (1 inch) of topsoil removed, and 7.62 cm (3 inches) of topsoil removed. After treatment. each plot was split and one-half treated to control competition using herbicide8 (a mixture of Goal. Garlon, and Roundup). First year data on the competition control by herbicides was found to be non-significant.

Treatment areas measuring 11.8 m by 23.0 m were laid out and the specified treatment8 were applied using a D-6 crawler tractor. After treatment. measurement areas of 6.2 m by 20.3 m were located in the center of the treated areas with the remainder of each treatment area maintained as a buffer zone.

1/ Paper presented at the Second Biennial Southern Silvicultural Research Conference, Atlanta. Georgia. November 4-5, 1982.
2/ The authors are Research Associate. Associate Professor, and Assistant Professor, Department of Forestry, Alabama Agricultural Experiment Station, Auburn University. Auburn, Alabama.

The **study** sites were hand planted using 1-0 loblolly pine (*Pinus taeda* L.) seedlings at a spacing of 1.83 m x 2.44 m (6x8 ft. 2240 trees/ha) within two weeks of treatment. A minimum of one row of seedlings was left outside of the measurement area on all sides to act as a buffer. After planting. the height of each seedling was recorded. At the end of the growing season, seedling survival and heights were again measured.

Soil Sampling and Analysis

Soil samples for nutrient analyses were collected at three random locations in each measurement plot. At each sample point. the upper 15.24 cm (6 inches) of soil was sampled by taking two successive 7.62 cm incremental cores 7.62 cm in diameter, For each plot.. the separate incremental samples were composited over the three locations for analysis. The values obtained for the two levels were then averaged to determine the soil values for the upper 15.62 cm. These samples were collected immediately after planting and also at the end of the first growing season.

Soil samples were prepared for analysis by air drying, grinding. and sieving through a 2 mm sieve. After sieving. soil organic matter was determined using the Walkley-Black procedure (Jackson 1958; Allison 1965). Ca, Mg, K, and Mn were extracted using 1 N ammonium acetate adjusted to pH 7.0 (Chapman 1965) and their concentrations determined using atomic absorption spectrophotometry. Strontium chloride was added to the extracts prior to the determinations for Ca and Mg (David 1960). Cation exchange capacity was calculated using exchangeable acidity determined using the Adams - Evans buffering system (Adams and Evans 1962; Hajek et al. 1972) and summation of Ca, Mg, and K values. From this, base saturation was computed. Available soil P was extracted using a dilute double acid solution (Bray and Kurtz 2) and obtained using the chlorostannous - reduced molybdophosphoric blue color method (Jackson 1958).

Soil bulk density was determined for only the upper 1.62 cm of soil using the core method described by Blake (1965). A 347.6 cm3 ring sampler was used to collect five cores from each plot after treatment and at the end of the first growing season. The five values were then averaged to obtain the bulk density within a plot at each sampling time.

Data Analysis

The soil and seedling data collected was analyzed using analysis of variance and Duncan's multiple range tests of the Statistical Analysis System (Barr et al. 1979).

RESULTS AND DISCUSSION

Soil Data

After one growing season. nutrient levels for treatments where 2.54 cm at 7.62 cm were removed were significantly lower than the control for Mg, K, and Mn (Table 1). However. there was no difference in nutrient values between the two removal treatments for any of the nutrients. Ca and P levels were lower than the control only for the 7.62 cm removal treatment.

The nutrient decreases observed are probably attributable to organic matter removal. Soil organic matter content significantly decreased where topsoil was removed (Table 1). Upon decay. this organic matter would normally supply large quantities of nutrients to the root systems of the planted seedlings (Pritchett 1979; Bengston 1981). Greenhouse studies on slash pine have confirmed the effect of organic matter loss on nutrient losses (Brendemuhl 1967).

Bulk density on all treated plots was significantly higher than on the controls. Compaction resulting from the equipment used to remove the topsoil is the probable explanation. However, no bulk density difference was observed between the two levels of topsoil removal.

Nutrient values at the end of the first growing season were compared with values obtained at planting time to determine if any changes occurred over time (Table 2). Except for Ca and Mg, soil nutrient levels were not significantly different for the two sampling times although the measured values were lower for the two removal treatments. Mg alone significantly decreased over the first growing season for all treatments. The Mg reduction is attributable to some leaching losses which have been reported to occur in the immediate area (Gordon et al. 1980). The reason for the lack of a significant decrease over time for the other nutrients is not clear.

TABLE 1 - Mean soil nutrient levels, organic matter content, and bulk density for the three treatments at the end of the first growing season. Means with the same letter are not significantly different at the 0.05 level.

TREATMENT[1/]	P	Ca	Mg	K	Mn	Base Saturation	Organic Matter	Bulk Density
	ppm	meq/100g				%		g/cc
Control	3.65 A	0.24 A	0.34 A	0.14 A	0.06 A	39.3 A	1.89 A	1.30 B
2.54 cm removal	3.14 A B	0.24 A B	0.26 B	0.09 B	0.03 B	35.3 B	1.21 B	1.50 A
7.62 cm removal	2.52 B	0.20 B	0.21 B	0.08 B	0.03 B	34.0 B	0.86 B	1.56 A

1/ Treatment indicates amount of topsoil removed. For the control, no topsoil was removed.

TABLE 2 - Mean soil nutrient levels, organic matter content, and bulk density for each treatment at planting and at the end of the first growing season. Means with the same letter are not significantly different at the 0.05 level.

TREATMENT[1/]	TIME	P	Ca	Mg	K	Mn	Base Saturation	Organic Matter	Bulk Density
		ppm	meq/100g				%		g/cc
Control	Planting	3.86 A	0.15 B	0.58 A	0.13 A	0.05 A	40.2 A	1.72 A	1.47 A
	1 Season	3.65 A	0.24 A	0.34 B	0.14 A	0.06 A	39.3 A	1.89 A	1.30 B
2.54 cm removal	Planting	3.36 A	0.19 B	0.56 A	0.11 A	0.04 A	40.2 A	1.46 A	1.55 A
	1 Season	3.14 A	0.24 A	0.26 B	0.09 A	0.03 A	35.3 B	1.21 B	1.50 B
7.62 cm removal	Planting	2.51 A	0.11 B	0.46 A	0.09 A	0.03 A	36.1 A	0.95 A	1.61 A
	1 Season	2.52 A	0.20 A	0.21 B	0.08 A	0.03 A	34.0 A	0.86 A	1.56 B

1/ Treatment indicates amount of topsoil removed. For the control, no topsoil was removed.

Ca levels oa all plotr increased duriag the firrt growing season. However, the reasons for this increase have aot been ascertained. Retesting of samples ha8 not uncovered Any error8 in CA analysis.

Organic matter content of the roil decreased between planting time and the ead of the first growing season for the 2.54 cm treatment. Little change might be expected for the 7.62 cm treatment, since the level of organic matter was already quite low due to it8 removal with the topsoil. The 2.54 cm treatment, however, removed topsoil but left many of the fine feeder root8 which would be classified A8 roil organic matter At planting time. But, over the growing season these fine root8 decomposed, thus reducing organic matter content of the soil oa there plotr.

Surface roil bulk density decreased for all treetmeatr over the firrt growing season. This decrease is probably due to vegetative root expansion reducing compaction which had occurred duriag treatment or logging. The length of time needed for complete recovery from compaction is uncertain, but other studies have provided estimates of 18 to 40 years (Perry 1964; Hatchell and Ralston 1971).

Seedling Survival ead Growth

Survival for seedlings planted on the treated areas was higher than oa the control (Table 3). Thir is most easily explained as being due to the reduction in the level of competition, which would lead to an increase in water available to the planted seedlings (Zähner 1958; Moehriag 1977). However, there was no diff ereace in survival betweea the 2.54 cm And the 7.62 cm removal treatments.

After oae season, reedliag height and growth were not found to be significantly Affected by the amount of topsoil removed. This may be due to the large variation in seedling height8 which occurred. Much of this was due to tip dieback And damage by deer and insects. Future measurements will be made to determine whether difference8 in growth do develop due to differences in roil nutrient status, bulk density, and organic matter content.

CONCLUSIONS

After oae growing season, the autrieat status was significantly reduced where topsoil wae removed. Sample means indicate a tread toward higher nutrient differences A8 the quantity of topsoil removed increased. The nutrient losses occurring Are probably due to leaching of the88 nutrient8 from the upper roil layer, where they are readily available to a majority Of reedliag roots. As a result of reduced competition, reedliag survival increased where topsoil was removed. However, the seedling height8 and growth did not increase.

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TABLE 3 - Mean height. survival, and growth of planted loblolly pine seedlings at the end of the firrt growing season. Means with the same letter Are not significantly different at the 0.05 level.

TREATMENT1/	Tote1 Height	Survival	Height Growth
	cm	%	cm
Control	30.47 A	65 B	19.13 A
2.54 cm removal	37.39 A	79 A	18.02 A
7.62 cm removal	36.10 A	82 A	17.59 A

1/ Treatmeat iadicater quantity of topsoil removed. For the control, no topsoil was removed.

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FIRST-YEAR EFFECTS OF ROOTRAKING ON AVAILABLE NUTRIENTS IN PIEDMONT PLATEAU SOILS"

R. E. Banker, J. H. Miller, and D. E. Davis 2/

Abstract .--The effects of rootraking on the levels of Ca, Mg, K, PO4 and Na and on infiltration rates in Piedmont Plateau soils were investigated. Soil samples were taken before and after treatments at lo-foot intervals along permanent 100-foot lines located on the ridge, upper slope and lower slopes. Samples were taken at O-2, 2-4, 4-6, 6-12, 12-18 and 18-24 in. depths and composited. Infiltration rates *were* measured with a double-ring infiltrometer. There was a general tendency toward nutrient increase at almost all depths with some differences significant at the 5 and 10% levels. A major increase in the PO4 content was found at the 4-6 and 6-12 in depths. Infiltration rates decreased.

Over recent years the use of heavy machinery in forest site preparation has increased. KG blades and rootrakes are now commonly used for windrowing treatments on the rolling sites of the Piedmont Plateau. Of the two treatments, rootraking seems to have the most potential for damaging the soil due to the resulting tillage impact on easily-erodible sites. Drastic decreases in soil nutrients could be counterproductive, offsetting the short-term benefits of these treatments.

The effects of selected site preparation treatments on Piedmont Plateau soils have been investigated by Campbell (1971). In his study, sites were treated with a single chopping, two single choppings or double chopping. No significant differences between treatments were found in available Ca, K or P or in bulk density. Campbell (1973) also tested the effects of harrowing, bedding, and chopping. Bedding increased available Ca, K and P, and harrowing increased Ca and P. Minor increases in Ca were reported with chopping. Chopping had no effect on bulk density while both harrowing and bedding lowered bulk densities. Thus, treatments having a tillage affect increased major nutrients while chopping increased Ca only.

Glass (1976) investigated the effects of rootraking on site quality of Piedmont soils. Soil characteristics and the volume of usable wood produced were compared using a 17-yr old rootraked area and an adjacent broadcast-burned area. Windrows were also compared with the intervening area. Soil texture, nutrient, and organic matter analyses substantiated his observation that the windrows contained not only logging slash and other debris, but also substantial quantities of topsoil. There is no information available on the early effects of rootraking on soil nutrients or infiltration.

We have initiated a 10-yr study, the objective of which is to investigate the effects of rootraking on the fine-textured soils of the Piedmont Plateau.

Materials and Methods

Study areas were made available by private industry in Georgia. Three of the sites were located in Heard County, and one in each of Talbot and Baldwin Counties. A representative slope was selected for study on each site (Table 1).

The study areas were sampled at the beginning of the experiment and again 3-4 months after treatment. They will be resampled at 2, 3, 4,

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Table 1. Study slope characteristics

Study area	Soil series	% Slope	Aspect
Beard County:			
Ricks tract	Cecil	15	East
Sall Hull tract	Madison	9	Northeast
Denny tract	Pacolet	16	Southeast
Talbot County	Vance	10	South
Baldwin County	Cecil	12	South

6, 8 and 10 years. One hundred-ft lines were established at each study slope on the ridge, upper slope and lower slope. Two points off the study area were permanently marked for each line. Triangulation from these points was used to relocate the original lines after treatment. Soil samples were collected at 10-ft intervals along each 100-ft line (11 points). Samples were taken with a Lord tube sampler at depths of 0-6, 6-12, 12-18 and 18-24 inches. The 0-6 in. sample was subdivided into 0-2, 2-4 and 4-6 in. depths. A hand auger was used when dry conditions made it impossible to use the tube sampler. All samples from a given depth along each line were composited. Samples were air dried and then crushed to pass a 2mm-mesh sieve.

Duplicate, 5-g samples were extracted with a double-acid solution of 0.05 N hydrochloric acid and 0.025 N sulfuric acid (Mehlich 1953). Standard techniques of atomic absorption spectrophotometry were used to determine concentrations of Ca, Mg, K and Na. Phosphate was assayed by the ascorbic acid method (Watonabe and Olsen 1965).

Table 2. Mean values of soil nutrients before (B) and after (A) windrowing treatments in Piedmont soils 1/

Depth	PO_4		Ca		Mg		K		Na	
	B	A	B	A	B	A	B	A	B	A
(inches)	(parts per million)									
0-2	1.04	1.24	365	330	12.2	21.7	12.2	14.0	6.9	8.5
2-4	0.40	0.68	193	234	8.4	9.9	7.6	8.7	5.9	8.7
4-6	0.31	1.36	154	222	8.2	10.7	6.8	7.5	5.3	7.5
6-12	0.13	0.54	173	192	9.4	17.5	5.9	6.2	5.6	6.7
12-18	0.16	0.46	163	187	10.5	13.0	5.0	4.8	5.9	6.7
18-24	0.20	0.58	151	166	10.4	21.1	4.6	4.5	6.0	7.7

1/ Two underlines indicate a significant difference at the 5% level and 1 underline, the 10% level.

A double-ring infiltrometer (Haise 1956) was used to measure infiltration on the Talbot County study area. Three infiltration readings were taken at each of the ridge, upper slope and lower slope. Infiltration was measured over a 2-hour period.

Results and Discussion

Analyses of Variance established that there was no significant effect from slope except at the 18-24 in. depth for Ca ($P < .05$). Thus, data for the slopes were pooled and comparisons between before and after treatments were performed. Table 2 shows mean values for the nutrients tested.

Although not all differences were statistically significant, there was a general tendency after windrowing toward increases for all elements at almost all depths. The PO_4 increases were particularly interesting because phospherous is often a limiting factor in growth. At the 4-6 and 6-12 in. depths there were particularly large increases. The increased availability of P at these depths could be beneficial to seedling establishment. However, these results show extremely low P levels at all depths. Due to time of sampling, these differences could be attributed to seasonal changes.

Explanations for these increases would be purely speculative at this time. Possible explanations could include an increase from mineralization, a decrease in plant uptake, and decomposition and mineralization of root materials. This could account for increases even at the lower depths. We are presently analyzing organic matter and N data and these will be reported later.

Mean 2-hr. infiltration rates for each slope before and after rootraking were ridge = 4 and 2 gal, upper slope = 7 and 2 gal, lower slope 17 and 4 gal, respectively. This is interesting in that Campbell (1971) and Grelon (1959) found that site preparation reduced bulk density, thereby increasing infiltration. However, this was not the case in this study.

A decrease in infiltration could be the direct result of the method of site preparation on the study area tested. The company owning the land parked their equipment nightly on the ridge where the upper line was established. The windrow was established so that it ran across the contour of the slope rather than with the contour. Because of this, the windrow intersected the lines on both the upper and lower slopes. Repeated passes were made across these established lines as the tractors moved material to the windrows. This could account for increased compaction, increased bulk density and, therefore, decreased infiltration.

Summary

Significant increases in available nutrients at the 5 and 10% levels of probability were seen for Mg at the 18-24 in. depth, K at the 0-2 in. depth, P at all depths, and Na at 2-4, 4-6, and 18-24 in. depths. There was a major increase in P at the 4-6 and 6-12 in. depth. There was a general tendency towards increases in all available nutrients tested at almost all depths. Accompanying these changes in nutrient levels, there was decreased infiltration of the soils.

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ROOT DEVELOPMENT OF LOBLOLLY PINE SEEDLINGS IN COMPACTED SOILS[1/]

Gerry L. Simmons and Andrew W. Ezell[2/]

Abstract.--Loblolly pine seedling root responses to various levels of soil compaction were investigated on two study sites in East Texas. Seedlings were grown in field conditions and in a maintained environment situation. Bulk density increased 11 percent at one site and 10 percent at the other after one vehicle pass over the area, but showed a negligible increase after a second pass. Seedling root growth generally decreased with an increase in bulk density.

INTRODUCTION

Roots play an important role in the survival and productive potential of forest trees by providing anchorage, water and nutrients needed for growth and development (Bilan 1968). Due to its effect on the initial growth and development of root systems, compaction produced by heavy equipment used in harvesting and cultural operations will become even more important as pressures for increased forest production lead to more intensive management programs (Foil and Ralston 1967). The objectives of this study were to measure loblolly pine (*Pinus taeda* L.) seedling root responses to various degrees of soil compaction which occurred during a simulated mite preparation operation, and to evaluate the effects of this soil compaction on physical parameters of two soil types found on industry owned timberland in East Texas.

METHODS

Two sites were located on land owned and managed by Champion International Corporation. To simulate a site preparation operation a D-8 track-type tractor with a V-blade attached was used to apply compaction treatments at each site. The area designated as Compaction Level I was traversed once by the tractor and the area designated as Compaction Level II was traversed twice. At each site an undisturbed area was also established as a Control.

A sample of 150 nursery-grown 1-O loblolly pine seedlings from the same provenance were measured to determine length of lateral roots, volume of the root system, and shoot height. At the end of one growing season seedling parameters were remeasured and the percent change for each parameter was determined.

Twenty-five seedlings were hand planted on each treatment area at both sites. On compacted areas seedlings were planted in the tracks caused by the tractor tranversing the area. Fifteen seedlings from each treatment remained in the field until the end of the growing season.

The other ten seedlings from each treatment were transported undisturbed to the laboratory in PVC pipe containers. The sixty transported seedlings were positioned by random methods into six rows outside the laboratory. Sand was used to fill the space surrounding the containers, providing insulation against radiation which would have heated the sides of the containers. Soil moisture tension was monitored with tensiometers and when the average tension reached 70 centibars the soil was saturated again.

Particle size analysis of the top 18 inches in each soil horizon was determined using the Bouyoucos hydrometer method (Black 1965). Bulk density was determined for the 0-3, 3-6, and 6-9 inch soil layers using the core method (Black 1965). Volumetric water content was determined for both sites immediately prior to compaction.

The water retention capacity for each treatment was determined at 1/3 bar and 15 bars of soil moisture tension using the tension plate method (Black 1965). Using this data the available water content (cm^3/cm^3) was estimated by calculating the

1/ Paper presented at Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia. November 4-5, 1982.

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difference in water retention capacity between 1/3 bar and 15 bars of soil moisture tension.

Analysis of variance was used to test for significant ($P<0.05$) seedling response differences between locations (field vs. lab) and sites and among treatments. Separate analyses of variance were also performed for field grown seedlings and lab grown seedlings. Analysis of variance was also used to test for significant ($P<0.05$) bulk density differences between sites and among treatments and depths. All analysis of variance models were considered fixed.

RESULTS AND DISCUSSION

Soil Parameters

Textural analyses for Site I revealed a sandy loam surface layer (0-6 in.) overlying a subsurface layer (6-18 in.) ranging from loam to sandy clay loam. At Site II the texture ranged from loamy sand to sandy loam throughout the profile.

The average soil water content (cm^3/cm^3) at Site I exceeded field capacity water content at the time of compaction. Site II had an average soil water content very slightly below that of field capacity. Due to the lesser percent sand on Site I, this site had a higher water retention capacity and consequently a greater potential available water content than did Site II.

Analysis of variance showed significant differences for bulk density values between sites and treatments and among depths. At both sites the bulk density increased with an increase in depth on all treatments and when depths were averaged the bulk density increased with increased compaction. Values were higher for all treatments on Site II, probably due to the increased sand content on this site.

On both sites the bulk densities for the top nine inches of each soil profile increased the most between the Control and Compaction Level I. On Site I the Control had a bulk density of 1.28 g/cm^3. This value increased 11 percent to 1.42 g/cm^3 on Compaction Level I. Compaction Level II had a bulk density of 1.43 g/cm^3, which was only 0.7 percent greater than that of Compaction Level I. On Site II the bulk density for the Control was 1.38 g/cm^3. The bulk density for Compaction Level I was 1.52, a 10 percent increase over that of the Control. Compaction Level II bulk density only increased an additional 1.3 percent to 1.54 g/cm^3.

Seedling Responses

Analysis of variance of the percent change in the lateral root length showed significant differences between locations and sites, and a significant location x site interaction term. A separate analysis of variance performed for seedlings grown in the field showed significant differences among treatments and sites. However, the analysis of variance for seedlings grown at the lab showed a significant difference only between sites.

These results suggest that on these sites, differences between sites and amount of soil compaction both influence lateral root elongation when seedlings are grown in the field. However, when seedlings are grown at the lab under monitored conditions, differences in lateral root growth are attributable primarily to site differences.

The significant location x site interaction term indicates that seedlings from different sites did not react in the same manner when grown under monitored conditions. Seedlings from Site II, which had a site index (age 50 years) of 65, grew much better at the lab than aid the seedlings grown in the field. Seedlings from Site I (SI_{50} = 100) which were grown at the lab also exhibited an increase in growth over field grown Site I seedlings. However, because Site I was a very good site and seedling growth in the field was good, the comparative growth differential exhibited by the lab seedlings was not as great as that shown by Site II lab seedlings.

Seedlings grown at the lab exhibited greater lateral root elongation than did the field grown seedlings. This greater percent increase in lab grown seedlings was also observed for all other measured variables and was probably attributable primarily to the lower soil moisture tension maintained at the lab.

At the lab the lateral root elongation of Site I seedlings decreased as soil compaction increased (table 1). The greatest growth differential occurred between the Control and Compaction Level I seedlings. Lab seedlings from Site II showed the least lateral root elongation on Compaction Level 1. The Control seedlings showed the greatest average increase, followed by Compaction Level II seedlings. This trend was also observed for Site II seedlings grown in the field.

Table 1.--Average percent change in lateral root growth for Site I and Site II seedlings by locations and treatments.

	SITE I		SITE II	
TREATMENT	LAB	FIELD	LAB	FIELD
CON	540	115	205	4
CL1	490	126	60	-20
CLII	480	25	97	-16

The low average percent changes associated with Compaction Level I on Site II for this and other variables was probably due to differences in planting techniques. Compaction Level I at Site II was the first treatment to be planted and the planting crew was inexperienced. Consequently, a lower quality planting job was performed on this treatment, which could have resulted in reduced survival and growth.

In the field the greatest average percent increase exhibited by Site I seedlings occurred on Compaction Level I (table 1). The mean for the Control seedlings dropped slightly, while that for Compaction Level II seedlings decreased almost 100 percent. Compaction Level I exhibited a greater water retention capacity than did the other two treatments on this site, which possibly resulted in slightly more prolific lateral root growth. Site II field seedlings showed little or no lateral root elongation on all treatments.

Differences between locations and sites and the location x site interaction were significant in the analysis of variance of the percent change in the root system volume. An analysis of variance of seedlings grown in the field showed significant differences among treatments and between sites. Again these results imply that in this study both site and treatment effects are important in determining percent change in volume occupied by the root system when seedlings are grown in the field. However, under monitored conditions the treatment effects become less important and site differences become the primary factor influencing changes in root volumes.

The root system volume decreased with increasing compaction for lab seedlings from Site I (table 2). Site II lab seedlings again displayed the least average percent increase on Compaction Level I. Field seedlings at both sites showed a decrease in volume with increasing compaction. On Site II a negative average percent change occurred on Compaction Level I and Compaction Level II for this and other variables. This probably occurred due to poor site conditions, in combination with the effects of soil compaction, which acted to inhibit growth almost entirely.

Table 2.--Average percent change in volume of water displaced by the root system for Site I and Site II seedlings by locations and treatments.

TREATMENT	SITE I LAB	SITE I FIELD	SITE II LAB	SITE II FIELD
CON	1207	157	247	53
CLI	1125	100	124	-38
CL11	861	35	163	-44

Analysis of variance of the percent change in shoot height for all seedlings showed significant differences between locations and sites and among treatments. In separate analysis both the field grown and the lab grown seedlings showed significant differences between sites and among treatments. These results imply that site differences and compaction effects both have a significant impact on the rate of root elongation. Shoot growth trends were similar to lateral root elongation trends, with average shoot height decreasing as compaction increased.

Seedling survival was also determined for each treatment at each site and location. At the lab the Control and Compaction Level II seedlings from Site I had 100 percent survival and Compaction Level II had 90 percent. Site II lab seedlings had 100 percent survival on Compaction Level I, 80 percent on Compaction Level II and 70 percent on the Control. The lower survival on the Control probably resulted from the accidental loss of soil from two containers during transportation. In the field site I had 100 percent survival on the Control and Compaction Level I areas and 90 percent on Compaction Level II. Survival decreased on Site II to 47 percent on the Control, 33 percent on Compaction Level I and 53 percent on Compaction Level II.

SUMMARY AND CONCLUSIONS

This study was conducted on sites having fine sandy loam and gravelly loamy fine sand textures. Compaction applied when the soil moisture content was equal to or exceeding that of field capacity resulted in the greatest bulk density increase with one vehicle trip over the area on both sites. The second trip resulted in very little bulk density increases. Because of the high sand content of the study site soils and the high soil water content at the time of compaction, the initial bulk densities and changes in bulk densities due to compaction treatments were probably higher than would be observed on drier sites or on sites with finer textured soils. However, because of the similarity of many soils in East Texas to the sandy loam and loamy sand soils on the study sites, these results can probably be used in a qualitative manner to predict general seedling root responses to increased bulk density on these types of soils under similar moisture conditions.

Generally, seedling growth means decreased with an increase in bulk density. The poor growth encountered on compaction treatments having higher bulk densities was probably due to some combination of the following factors: increased mechanical resistance to root elongation, a decrease in macropore volume, poor aeration, and slower infiltration and internal movement of soil water.

Lab seedlings from both sites exhibited much higher growth means than those seedlings grown in the field due to the low soil moisture tension at the lab. However, the differences among compaction treatments at the lab were usually not as great as differences between sites. This implies that the effects of soil compaction are not as important as site differences in determining seedling growth responses when seedlings are supplied with adequate water.

The results of this study suggest that site conditions and soil compaction caused by heavy equipment prior to planting are both very important in determining seedling establishment and growth on sandy loam and loamy sand soils during the first growing season. Because larger increases in bulk density occur on sandy soils which are at or near field capacity, sites having these characteristics should not be traversed during wet weather conditions if possible. However, sites having sandy soils are usually harvested or prepared for planting during wet weather when sites having heavier textured soils are inaccessible. Under these circumstances traffic should be limited to a minimum number of orimarv trails. Since additional vehicle trips seem to cause very little increase in bulk density under these conditions, the area subjected to higher bulk densities would thus be minimized.

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HANDPLANTING COSTS ARE INFLUENCED BY PLANTING SITE CHARACTERISTICS[1/]

Richard W. Guldin [2/]

Abstract.--The primary artificial regeneration method used for southern pine is planting seedlings by hand. While improvements in survival, growth and yield from more intensive site preparation have been heavily studied, the effect of intensive treatments on total regeneration cost has drawn little attention. From 70 planting contracts for both national forests and industrial lands, a regression equation is developed that relates planting site characteristics and preparation activities to planting cost. It contains six independent variables: two acreage variables, three treatment variables, and type of ownership. The analysis provides guides for more efficient regeneration decisions.

The past 2 years have been exceptionally difficult ones for the southern pine industry. Markets have been poor and sales low. Consequently, budgets for reforestation have been tightly squeezed.

This paper explores ways in which the type and intensity of site preparation affect subsequent costs of handplanting southern pine seedlings on national forests and industry lands.

Site preparation procedures vary widely, depending in large part on landowner objectives and policies. It is not unusual for 2 adjacent landowners to use widely differing site preparation methods. The Francis Marion National Forest in South Carolina favors a single drum chopping treatment coupled with herbicide injections of trees too big to chop. On adjacent private land, similar sites are either being sheared, raked and bedded; or sheared, chopped, burned and bedded before handplanting. Private landowners spent up to twice as much per acre for site preparation as the national forest. However, the national forest spent more to get its sites handplanted, even though the planting methods were generally the same.

To explore the relationship between site preparation and planting investments, site characteristics and preparation practices were reviewed for 70 separate planting sites. The sites covered 11,633 acres in 230 individual parcels on 8 national forests and 6 industrial ownerships. Both coastal plain and piedmont sites in South Carolina, Alabama, Mississippi and Louisiana were included.

Data were collected for sites planted in both the 1979-1980 (25%) and 1980-1981 (75%) seasons. Contractors performed all of the planting and site preparation activities except prescribed burning --on both public and private lands.

Contract costs are preferred for analysis instead of "in house" or "force account" estimates because contract costs were established by the market and not by accounting practices.

ANALYSIS

Handplanting cost per acre, excluding the cost of seedlings, was selected as the dependent variable for regression analysis. From the 13 categories of information considered as potential independent variables, Equation 1 was obtained.

The F-statistic for the equation is 23.58, having a probability less than 0.001. The coefficient of multiple determination (R^2) is 0.69. The standard error of the estimate is 8.02. The t-statistics, shown in parentheses beneath the coefficients, are all significant, having probability less than 0.008.

1/ Paper presented at 2nd Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Equation 1.

$$\text{HANDPLT\$} = \$2.00 - \$0.040\ (\text{TOTLACRE}) + \$17.20\ (\text{LOGACRE})$$
$$\qquad (2.85) \qquad\qquad (3.24)$$

$$- \$3.75\ (\#\text{MACHPAS}) + \$7.91\ (\text{BURNED}) - \$0.49\ (\text{BURNCOST})$$
$$(2.90) \qquad\qquad (2.72) \qquad\qquad (4.08)$$

$$+ \$20.43\ (\text{OWNER})$$
$$(6.74)$$

Where:

HANDPLT$ - Handplanting cost, dollars per acre
TOTLACRE - Total acreage offered for planting
LOGACRE - Logarithm, base 10, of TOTLACRE
#MACHPAS - Number of machine passes used in site preparation
BURNED - Zero-one variable, 1 if broadcast burn was used
BURNCOST - Cost of prescribed broadcast burn, dollars per acre
OWNER - Zero-one variable, 1 if national forest, 0 if industry

DISCUSSION

Site preparation activities are directed at three goals: (1) controlling competing vegetation; (2) improving the seedling's growing location; and (3) simplifying planting (Smith 1962). Dollar benefits from controlling competition and improving the planting spot normally accrue as increases in future harvest value. Through economic formulas, the expected future harvest value can be discounted to an equivalent benefit value in today's dollars. Reductions in planting contract costs measure the dollar benefits obtained from simplified planting. The sum of the present worth of future harvest benefits and the reduction in planting cost must exceed the total cost of the site preparation treatments for the combination of site preparation treatments to be economically justified.

Although altering site preparation activities induces changes in benefits from all 3 goals, the equation only estimates the economic benefits from the simplified planting goal, i.e. a reduction in HANDPLT$. A separate economic analysis is required to measure the competition control and planting spot improvement benefits provided.

The independent variables fall into 3 categories: acreage, treatment and ownership.

Acreage

TOTLACRE and LOGACRE combined have a curvilinear effect on HANDPLT$. As the planting contract acreage increases up to 160 acres, the cost contribution of acreage to HANDPLT$ increases up to $31.60. Between 160 and 200 acres, the cost contribution to HANDPLT$ is constant. For areas larger than ZOO acres the net acreage contribution to HANDPLT$ declines.

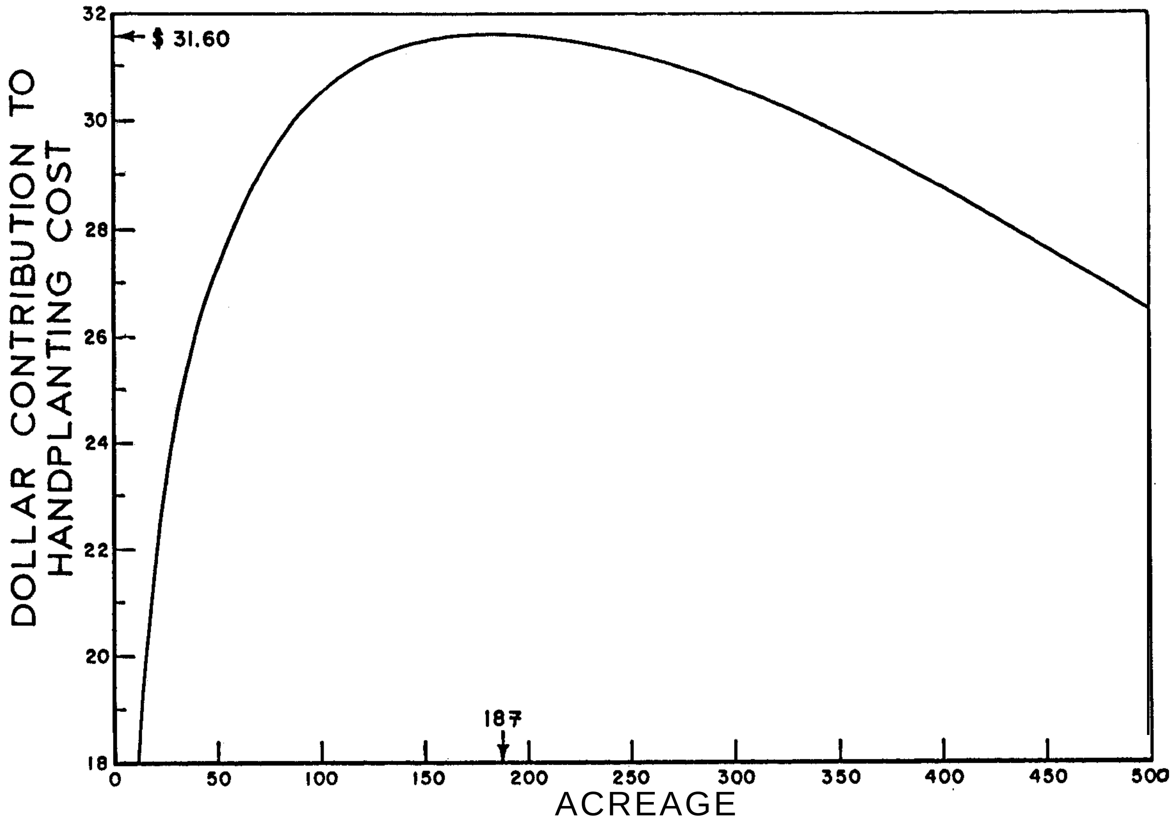
Differences in planting contractors are responsible for the cost peak between 160 and 200 acres (fig. 1). Contractors with a large permanent crew cannot economically plant small tracts because they spend too much time moving from site to site. Small acreages are usually planted by small local contractors. But as acreage increases (up to 200 acres), a small contractor has to hire temporary laborers or work overtime to get the job finished on time. Hiring temporaries and working overtime both reduce planting efficiency and increase costs. As contract acreage increases, a point is finally reached (160 acres) where a contractor with a large permanent crew can plant the area economically. Between 160 and 200 acres, large and small contractors are directly competing for the low bid.

Treatments

The forest product firms studied began site preparation with shearing on 81 percent of the sites. They used bedding on 41 percent of the sites and broadcast burning on 33 percent of the sites. National forest managers used shearing as the initial treatment on only 19 percent of the sites. They never bedded, but burned 48 percent of the sites. The principal preparation method used by national forests was injection of herbicides with hand tools (53 percent of the sitesj. Consequently, preparation of industrial land was more intensive, using an average of 2.1 machine passes compared to 0.5 machine passes for national forests.

The coefficient of #MACHPAS reveals that each additional mechanical site preparation treatment reduces HANDPLT$ by $3.75 per acre. For example,

Figure 1.--The effect of contract acreage on HANDPLT$



if bedding costs $20 per acre, it would reduce HANDPLT$ $3.75 (simplified planting benefits) because between-row spacings have already been established by the beds. Only $16.25 remains to be justified by present worth benefits from competition control and site amelioration.

The two burning variables combine to reduce HANDPLT$ when burning costs more than $16.01 per acre. Several firms burn to facilitate planting. But the present worth benefits from low-cost burning are not captured in reduced planting costs. Because low-cost burning actually raised HANDPLT$, present worth benefits from competition control and planting spot improvement must be greater than the sum of the cost of burning plus the increase in HANDPLT$.

High burning costs were common where hand injection of herbicides was used for overstory competition control instead of shearing. Such sites tended to have heavier fuel accumulations. On these sites, burning did not merely kill sprouts and eliminate herbaceous competition, it also replaced mechanical treatments to destroy harvest residues and thereby simplify planting. Whether a burn or an additional mechanical treatment has a greater net present worth depends on the interaction of benefits from competition control spot improvement.

Owner

The coefficient of the OWNER variable indicacates that planting the same sized site prepared the same way will cost $20.43 per acre more if the acreage is national forest than in industrial ownership. The increased cost of Forest Service planting contracts is not the result of inconsistent data. Some of the planting contractors did business with both, and the bids were always higher for national forest contracts.

Five factors contribute to the difference in handplanting bid prices between the two ownerships: 1) harvest utilization standards, 2) harvest tract size differences, 3) visual amenity consequences, 4) seedling spacings and 5) contract administration procedures.

Harvest Utilization Standards stem from differences in harvesting philosophy and emphasis. Southern forest products firms leave less material on the site following harvest. The recent emphasis in energy self-sufficiency has led many firms to install wood-burning boilers for steam and electricity generation. Mill waste is insufficient to meet total fuel needs in most cases, so logging waste and small trees previously left on the site are now chipped and hauled to the mill for fuel. On national forests, contract specifications frequently limit the cutting of small fuelwood trees. Although small stems may be cut by private individuals having firewood collection permits, such fuelwood harvesting is not nearly as complete as industrial chipping of residuals. The result is more stems and harvest debris left to hinder the site preparation and planting process on national forest land than on industrial-owner lands.

Harvest tract sizes differ between ownership classes. Although the average planting contract acreages are similar (143.8 acres for industry and 180.4 for national forests), the average tract size for industrial land is 138.7 acres compared to only 50.6 acres on national forests. National forests tend to lump several small parcels together into one planting contract.

Small tract sizes are more costly to plant. Time is spent moving the crew and laying out the job before beginning work at each site. If more than one tract is being planted simultaneously, costs increase because the foreman spends less time supervising planting crews because of commuting between sites. Decreased supervision may result in slower progress of the crews (raising overhead costs per acre), lower quality of work and increased need for interplanting.

Visual amenity consequences of harvest have led the Forest Service to use irregularly shaped parcels to minimize the visual impacts of harvest cutting. The results are large increases in parcel perimeter per unit acre and concommitant increases in planting difficulty. Irregular shapes create and cut off short lengths of row along the perimeter if rows are laid out parallel to the parcel's longest axis. Alternatively, rows may twist and turn to follow the parcel's boundary. In either case, keeping the proper spacing between and within rows is difficult. Bringing crews back to areas needing interplanting to bring planting density up to minimum levels is costly. The alternative is to plant more trees to assure meeting stocking minimums, which results in slower progress.

Seedling spacings differ between ownerships although the mean number of seedlings planted per acre is comparable between ownerships(± 10 percent). Cost differences due to planting density per acre, although minor, should favor national forests because they plant fewer seedlings per acre. But the same seedling density can be obtained with different spacings. Planters walk 20 percent less row when the spacing between rows is 10 feet versus 8 feet to plant at the same density per acre. The lo-foot spacing between rows is favored by industry and the Kisatchie National Forest, LA. The other national forests favored 8-foot spacings.

Contract administration procedures influence the OWNER coefficient through 2 elements: the bidding mechanism and the documentation mechanism. Sealed bidding for contract planting, required on national forests, leaves no latitude for negotiating a lower price with bidders. Industries, on the other hand, negotiate contract prices. They can add perquisites in the form of guaranteed minimum acreages or preferences on future contracts and reward good performance. All these factors can result in lower bid prices for industry land than for federal land.

National forest contracts require more documentation than industry contracts. Each time the contract officer or his representative contacts the contractor, a written record is created. The contractor is required to initial or sign forms, of ten daily. Many planting contractors reflect their feelings about such thorough documentation by raising the bid prices higher than those charged on industrial ownerships where less documentation is required.

SUMMARY

There is a strong negative association between handplanting cost and intensity of site preparation. The higher cost of handplanting national forests compared to industry lands appears due to sites that have more harvest residuals obstructing planter access, that are smaller and more irregularly shaped, and that are planted at less efficient spacings. The lower intensity of mechanical site preparation on national forests and contract administration procedures also add to the planting cost premium.

Land managers can use the results of the analysis as guidelines for evaluating the efficiency of their regeneration programs. By considering the effects that site preparation methods and harvest tract size have on handplanting cost, today's scarce regeneration funds can be stretched to expand the acreage reforested and help assure future timber supplies.

EFFECT OF SITE PREPARATION AND FERTILIZATION ON SLASH PINE GROWING ON A GOOD SITE [1/]

Allan E. Tiarks [2/]

Abstract.--Thirteen years after planting, slash pine (*Pinus elliottii* Engelm. var. *elliottii*) was still responding to a preplant application of 88 lb of phosphorus per acre. Bedding and flat disking improved height growth through age 13, but the effects of the site preparation treatments declined after age 10. Lime did not affect tree growth. Fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*) infection of the main stems was about 84 percent for all treatments. Still, the volume increase from phosphorus application and bedding compare favorably with the expected increase in volume on poorer sites now being operationally bedded and fertilfzed.

INTRODUCTION

The effects of bedding and phosphorus fertilizer on wet flatwood sites are usually dramatic, turning unproductive sites into productive ones (Pritchett 1979). However, this increase in growth from site modification must be compared to the increase that can be expected if the same expenditure were made on initially productive sites. Then the land manager can decide which of his sites will provide the greatest return, given the additional inputs.

This paper reports the effects of flat disking, bedding, phosphorus fertilizer, and liming on tree growth on a site that would produce a good crop without application of any of the site modifications.

METHODS

The study area was located in Rapides Parish, Louisiana, on a site occupied by native grasses and scattered small hardwoods. The soil is moderately well drained Beauregard silt loam (fine-silty, siliceous, thermic Plinthaquic Paleudult). The depth of the winter water table was estimated to be 18 to 28 inches using the depth to gray mottles as an indicator. Site index for slash at age 50 is 90, determined by using heights of the check plots at age 13 and site index curves (USDA Forest Service, 1976; Farrar, 1973).

Site preparation and fertilizer treatments were applied in a split plot design. Site preparation treatments, consisting of check, flat disking, and bedding, were applied to the main plots which were 116 x 148 feet. The check plots were burned several weeks before planting. The flat disked plots were tilled twice with an offset disk in the fall of 1967. Bedded plots were treated at the same time with a bedding harrow that formed ridges 6 inches higher than the original soil surface and 8 feet apart. Planting was delayed one season to allow the beds to settle.

Four fertilizer treatments were applied to subplots of each main plot. The treatments were no fertilizer, 1,000 lb/acre of lime, 88 lb/acre of phosphorus, and the lime and phosphorus treatments combined. The lime was agricultural lime less than 200 mesh and was applied to find the effects of increasing the amount of calcium on the exchange complex. Triple superphosphate was used as the phosphorus source. The fertilizers were broadcast by hand just before site preparation.

In February 1969, slash pine seedlings (1-0; grades 1 and 2) were planted at a 6- x d-foot spacing. At the end of the first growing season, all dead trees were replaced with l-l stock.

Measurements were made on 24 pines in the middle of each subplot. Heights were measured

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annually through age 5 and then at ages 7, 10, and 13. Diameter at breast height and fusiform rust infection measurements were begun at age 4 and from then on at the same time as height measurements. Reported diameters are quadratic means. Volume (inside bark) was calculated from the diameter and height of each tree using the equation:

$$V = 0.02408 + 0.0021058D^2H$$

(Schmitt and Bower, 1970). Fusiform rust infection was recorded if one or more galls had formed in the main stem. Mortality before age 4 was attributed to the establishment phase. Only trees alive at age 4 were used as a basis in calculating mortality and fusiform rust infection percentages.

Phosphorus and calcium concentrations in the needles were determined from samples collected in the winter, 2 years after planting, and in August, 10 years after planting. August sampling was used to maximize nutrient differences due to treatment. The foliar samples were dried at 70°C, ground to pass through a 20-mesh screen, ashed at 500°C and taken up in 0.3N HNO_3. Phosphorus was determined colorimetrically and calcium by atomic absorption spectrophotometry.

Available phosphorus and exchangeable calcium were measured on soil samples collected 13 years after planting. Available phosphorus was extracted by shaking with 0.05$\underline{N}$ HCl+0.025$\underline{N}$ H_2SO_4 for 15 minutes (Nelson et a1.1953, Wells et al.. 1973). Exchangeable calcium was removed with 1N NH_4OAc at pH 7.

Analysis of variance, including preplanned orthogonal comparisons, was used to test for differences with the significance level set at the 0.05 level. The arcsine transformation was used to normalize mortality and infection percentages.

RESULTS

Growth

The site preparation treatments and phosphorus fertilizer increased tree height through age 13. The mechanical and fertilizer treatments did not interact, so the effects of the two are additive.

The trees on the mechanically treated plots were significantly taller than the check plots beginning at age 3 (fig. 1). The bedding increased height by 1.0 feet at age 3 and by 2.1 feet at age 10. However, by age 13 the trees on bedded plots were only 1.4 feet taller than the trees on the check plots. The flat disking increased the height growth about half as much as the bedding treatment for ages 3 through 10. By age 13 the advantage of bedding over flat disking was no longer significant.

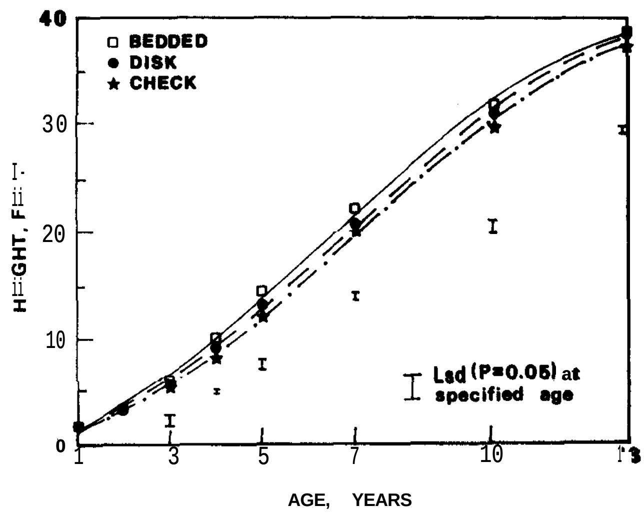

Figure l.--Effect of flat disking and bedding on height of slash pine stand 1 to 13 years old.

Bedding also increased tree diameter in the period before age 13 (table 1). Flat disking was marginally better than no mechanical site preparation for ages 4 through 10. Neither treatment was significantly better than the check by age 13. The standard error of the difference had almost doubled from 0.06 inch to 0.11 inch in the 3-year period. This accounted for the loss of significance rather than a decrease in growth differences.

Table 1 .--Effects of site preparation treatments on diameter and- volume of slash pine at ages 4 through 13 (average of all lime and phosphorus treatments)

Age	Average d.b.h.			Total volume (i.b.)		
	Check	Disk	Bed.	Check	Disk	Bed.
	--------inches--------			------(ft^3/acre)-------		
4	1.31a [1/]	1.56b	1.72b	33a	48ab	62b
5	2.34a	2.54ab	2.74a	137a	171ab	208b
7	3.71a	3.89b	4.08c	518a	584ab	666b
10	4.73a	4.91b	5.08c	1040a	1180b	1170b
13	5.64a	5.76a	5.98a	1560a	1750a	1670a

[1/] Means of common measurement age and type and followed by the same letter are not significantly different (P = 0.05).

The bedding treatments increased the total volume significantly in the first 10 years (table 1). The volume in the flat disked plots was significantly greater than on check plots only at age 10. Again by age 13 the effects of mechanical treatments were no longer significant. The effects of bedding and disking were 'no longer significant. Bedding and disking had equivalent effects on volume at all ages.

The phosphorus fertilizer applied during site preparation significantly increased the height of the trees by 7 to 10 percent beginning at age 4 (fig. 2). Phosphorus had increased total height by 0.6 foot at age 4 and by 2.5 feet at age 10. By age 13 the difference was 1.7 feet, a 5 percent advantage over the plots not receiving phosphorus fertilizer. These values were averages of all site preparation treatments.

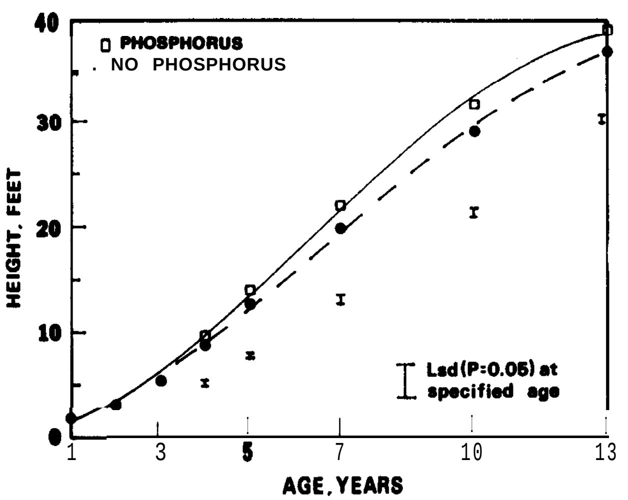

Figure 2.--Effect of phosphorus fertilizer applied 1 year before planting of slash pine on the height of the plantation

Diameter at breast height and volume were also consistently increased by phosphorus (table 2). The increase in diameter was similar to the increase in height, about 7 to 10 percent over the unfertilized plots. The increase in both height and diameter combined meant the total volume had been increased by more than 30 percent at ages 7 and 10. By age 13 the percent increase had been reduced to 23 percent. At age 13 the volume attributed to phosphorus fertilization was 347 ft^3/acre.

The lime treatment had no signficant direct effect on tree growth. Nor did the lime interact with the phosphorus fertilizer on mechanical site treatments to enhance their effects.

Table 2.--Effects of phosphorus fertilizer on diameter and volume of slash pine at ages 4 through 13 (average of all site preparation treatments)

Age	Average d.b.h.		Total volume (i.b.)	
	Check	Phosphorus	Check	Phosphorus
	------inches--------		------ft^3/acre--------	
4	1.48a[1/]	1.59b	44a	52b
5	2.41a	2.67b	151a	194b
7	3.64a	4.14b	498a	681b
10	4.65a	5.17b	971a	1283b
13	5.58a	6.01b	1487a	1834b

Z/Means of common measurement age and type and followed by the same letter are not significantly different (P = 0.05).

Fusiform Rust Infection

Rust infection in all of the plots was severe. Of all trees alive at age 4, about 84 percent had been infected or killed by rust at age 13 (fig. 3). Bedding had increased the incidence of rust over the other two site preparation treatments by 12 percentage points at age 4. By age 13 the difference in infection between bedding and the other two treatments was 7 percentage points which was significantly greater than any other treatment. The phosphorus and lime treatments did not consistently affect the incidence of fusiform rust. The percentage of trees infected was significantly lower on the phosphorus-treated plots at age 4 and on the lime-treated plots at ages 5 and 10. These differences in rust incidence are not consistent with the other measurement periods and do not appear to be meaningful.

By age 13, 31 percent of the trees alive at age 4 had died. The rate of mortality, expressed on the basis of number of trees alive at age 4, increased from 1.3 percent per year at age 5 to 4.3 percent per year at ages 10 and 13. Most of the mortality was associated with stem infection. None of the site preparation or fertilizer treatments affected mortality significantly and consistently with time.

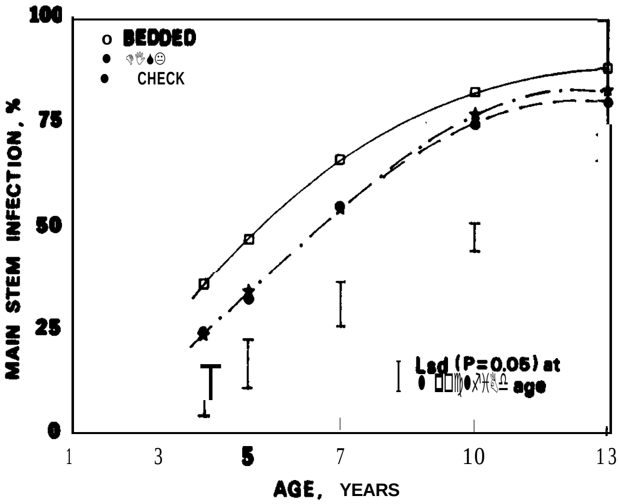

Figure 3.--Effect of site preparation on percentage of slash pine main stems infected with fusiform rust galls.

Nutrients in Foliage and Soil

The phosphorus fertilizer alone had increased the concentration of phosphorus in the foliage by 22 percent 2 years after planting and 3 years after application (table 3). By age 10 the plots that had received phosphorus fertilizer still contained significantly more phosphorus in the foliage compared to the controls. The added lime significantly reduced the phosphorus concentration in the foliage at age 2 or 3 years after treatment. By age 10, the lime had no effect on the phosphorus in the needles from plots not receiving phosphorus fertilizer. However, the lime significantly reduced phosphorus in the foliage of plots treated with both lime and phosphorus.

Table 3.--Concentration of phosphorus and calcium in slash needles 2 and 10 years after planting

Element	Age	Fertilizer applied: None	Phosphorus	Lime	Lime and Phosphorus
	-yr-	-g/kg-			
Phosphorus	2	0.85b[1]	1.04c	0.71a	0.85b
	10	0.57a	0.80c	0.57a	0.75b
Calcium	2	1.80a	1.90a	1.89a	1.98a
	10	1.07a	1.10a	1.07a	1.17a

[1]/Means in the same row and followed by the same letter are not significantly different (P = 0.05).

Neither lime nor phosphorus had an effect on calcium in the foliage at either sampling time.

At age 13, the soil in plots fertilized with phosphorus still contained significantly more acid extractable phosphorus (table 4). The lime treatment did not affect the available phosphorus in the soil.

Table 4.--Concentration of phosphorus and calcium in the soil and soil pH 13 years after planting

Measurement and units	Fertilizer applied: Nane	Phosphorus	Lime	Lime and Phosphorus
Mehlich 1 P, mg/kg	1.3 a[1]	2.5 b	1.5 a	2.3 b
Exchangeable Ca, meq/100 g	0.60a	0.62a	0.66a	1.00b
pH	4.11a	4.15ab	4.23c	4.29c

[1]/Means in the same row and followed by the same letter are not significantly different (P = 0.05)

The lime treatment had no effect on exchangeable calcium in the soil 13 years after application unless phosphorus fertilizer was also applied. However, the lime treatment increased soil pH by a small but statistically significant amount, independent of the phosphorus treatment.

DISCUSSION

The severe incidence of fusiform rust in the stand precludes growing susceptible slash pine on the site under any level of culture. The percentage of main stem infection without fertilizer or mechanical site preparation was 81 percent at age 13. While bedding caused a small increase in infection, the inherent level of infection is too high to make this a realistic difference. However, because rust often does not significantly affect tree growth until stem breakage occurs (Jones 1972, Nance et al. 1981), the growth data presented here should still be valid for comparison purposes.

The slash pine grew tallest on the bedded plots in the early measurement periods. But after age 10, the bedding treatment was not improving growth, In other studies where similar soils were bedded (Cain 1978, Haywood 1980), the early gain in growth was maintained but became insignificant as the stand increased in size. Also, in the present study the difficulty in measuring a small response in growth was confounded by a large mortality in later years. For example, the average diameter of trees which died between the ages of 10 and 13 was 4.4 and 4.0 inches for the bedded and check plots, respectively. This significant difference in the size of trees which died was caused mainly by random stem breakage at fusiform gall sites, causing greatest volume losses in plots with the largest trees.

The flat disking also caused a growth response from ages 4 through 10. While flat disking is usually credited with weed control (Haywood 1980, Pritchett 1979), it is difficult to relate the delayed response in this study to less competition. Perhaps both bedding and flat disking had an ameliorating effect on soil physical properties that enhanced growth from the time the trees had overtopped the competition until the pines had occupied the site. Further research is needed in this area.

The phosphorus fertilizer caused a significant and prolonged growth response after age 3. The response was probably delayed by grass and other herbaceous competition. Much of the applied phosphorus was retained on the site through age 13 as evidenced by the long-term growth response, increased available phosphorus in the soil, and increased phosphorus concentration in the foliage. However, 14 years after phosphorus fertilization the soil available P is below the critical limits set by Pritchett and Gooding (1975) of 4 to 6 ppm. Another phosphorus application would probably be required at age 10 for maximum production. Because the phosphorus was applied before site preparation, the phosphorus on the bedded and flat disked plots was incorporated, while it was only surface applied on the check plots. The lack of interaction between phosphorus and site preparation suggests that surface application of P is sufficient on these soils.

Langdon and Hatchell (1976) reported that slash pine did respond to liming when fertilized with phosphorus as well. Their soils originally contained from 0.2 to 1.5 meq/100 g of exchangeable calcium compared to about 0.6 meq/100 g in the present study. Thus, the lack of response to lime cannot be attributed to a higher calcium content in the soil. Other factors such as pH, stand age, or the availability of micronutrients probably caused the difference in response between their study and the present one.

Pritchett (1979) reported that by age 8, bedding and phosphorus fertilizer had increased volume by 688 ft^3/acre on a site that produced only 23 ft^3/acre without any treatment which is a very good relative increase. However, on the better site being reported on here, the check plot average interpolated to age 8 was about 80% of the best volume production reported by Pritchett (1979). Phosphorus fertilization and bedding at age 8 had increased volume by another 360 ft^3/acre. And the increase was in a fully stocked stand where treatments did not affect survival.

The land manager can use cultural practices to substantially improve production of both the very poor sites and good sites that are responsive to the inputs. On this moderately well drained site, bedding would not be a recommended practice. Phosphorus fertilizer has increased volume production sufficiently to make an economic analysis worthwhile. Such an analysis must include specific land managing concerns such as the value of concentrating wood production on a smaller acreage and the risk of treating unresponsive sites as well as the constantly changing costs of fertilizer and the price of timber. Therefore, a generalized recommendation for phosphorus fertilizer on similar sites is not possible. But using the cost of phosphorus fertilizer in 1967 and 1982 pulpwood prices the fertilization made a good return.

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SITE PREPARATION EFFECTS ON EARLY LOBLOLLY PINE GROWTH, HARDWOOD COMPETITION, AND SOIL PHYSICAL PROPERTIES [1/]

James N. DeWit and Thomas A. Terry [2/]

Abstract.--Height, diameter, and volume growth ranking of eight-year-old loblolly pine by site preparation method on Wilcox and Falkner soils in Kemper County, Miss., was as follows: shear-pile-bed > shear-pile > tree-crushed; hardwood basal area followed an exact opposite trend by site preparation method. Total hardwood plus pine basal area remained fairly constant among treatments; as hardwood basal area decreased pine basal area increased. Soil bulk density was greatest on shear-pile plots and soil macropore space was greatest on bedded plots. Hardwood competition and soil physical properties appeared to be limiting pine growth on the study site.

INTRODUCTION

The purpose of site preparation is to favorably modify the site for planting by reducing the level of logging residuals and competing vegetation and occasionally to ameliorate soil conditions. The choice of treatments to use to accomplish these objectives should be partially determined by the amount of residual vegetation and logging debris present, soil physical properties, and soil moisture conditions. Therefore, the critical step in treatment prescriptions is to identify those variables that are most limiting seedling survival and growth on a particular site.

One site preparation method which has been developed in the South to insure survival and enhance tree growth on wet sites is bedding. Survival trends on bedded versus flat-planted sites are inconsistent. Some researchers have found little to no advantage to bedding over flat-planting except on very poorly drained soils (McMinn 1969, Terry 1978, Derr and Mann 1977). Bedding has been demonstrated to increase survival by 10 percent (Terry and Hughes 1975) to 40 percent (Terry 1978) on very poorly drained soils but decreased survival by 10 percent to 20 percent on soils with sandy surface horizons and heavy root mats or on unsettled beds (Terry and Hughes 1975). The sandy surface and excessive vegetative debris can dry very quickly causing a newly planted tree to go into drought stress unless frequent rainfall occurs.

Numerous investigators have reported substantial gains in early growth of loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* var. *elliottii* Englem.) from bedding on wet sites (Baker 1973, Derr and Mann 1977, Mann and McGilvray 1974, McMinn 1969, and Terry 1978). However, height growth responses are quite variable by region and soil type (table 1). Bedding can provide long term growth advantages over alternative site preparation techniques on medium-to-fine textured soils in the Lower Coastal Plain where high winter and spring water tables can limit growth, summer droughts are infrequent, and soil physical properties are altered by tillage treatments. Pine growth response to bedding appears to be less than that obtained in the Lower Atlantic Coastal Plain on similar medium-to-fine textured soils in the Gulf Coastal Plain where summer droughts are frequent and chronically high water tables do not exist.

This early growth response to bedding has been attributed to numerous soil physical and chemical factors. The most important factor on poorly and very poorly drained sites probably is the improvement in soil drainage associated with the elevated microsite (McKee and Shoulders 1974, Terry and Hughes 1975). Also, the tillage action that occurs during bed construction increases macropore space and decreases bulk density (Terry 1978). Bedding also concentrates nutrients on a site by pulling the nutrient rich surface soil from the furrowed strips onto the beds

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Table 1. Pine plantation height growth comparisons among rite preparation methods on various wet sites.

Geographic Location	Soil-Site Description	specie.	Plantation Age	Single-Bed Comparison with	Height Advantage (m)	% Increase	Reference
Florid. Sendhill.	Lakeland Series	Slash Pine	6	Chopping	0.4	17	Baker (1973)
Florid., Lower Coastal Plain	Plummer Series	Slash Pine	8	Burn Only	1.1	29	Mann & McGilvray (1974)
South Florid.	Acid Soils	Slash Pine	5	no Treatment	0.8	34	McMinn (1969)
Northwest Florid.	Plummer Series	Slash Pin.	17 35	Undrained, Unbedded	3.3 1.7	28 a	Wilhite & Jon.. (1981)
I. Carolina Lower Coastal Plain	Leaf, Lenior	Loblolly Pine	7	K-G plus rootrake	1.4	60	Terry (1978)
	Bladen, Leaf, Lenior, Rains, Onslow, Lynchburg Series	Loblolly Pin.	3	K-G plu. rootrake	0.02-0.7 over four locations	4-86 over four locations	Terry & Hughes (1975)
	Bladen	Loblolly Pill.	18	K-G plus rootrek.	2.4	19	Hughes et al. (1979)
S. Carolina Lower Coastal Plain	Sandy loam over sandy clay	Loblolly Pine	7	K-G only	1.3	20	Westvaco Res. Rep. No. 66 (1973) Unpbl.
Alabama Interior Flatwoods	Wilcox Series	Loblolly pine	10	Sheer & Bum	0.9	13	Amer. Can Rep. us-35 (1980) Unpbl.
Mississippi Coastal Flatwoods	Atmore Series	Loblolly Pine	5	no Treatment	0.8	loo	Haines & Haines (1977)
caner.1 Louisiana	Beauregard, Wrightsville, Caddo Series	Loblolly Pine	5	no Treatment	0.3-0.5 over four locations	12-35 over four locations	Derr & Mann (1977)
			10	no Treatment	0.4-1.0 over four locations	7-23 over four locations	

(Schultz 1976), thereby making a relatively large nutrient pool available to the planted seedlings (Haines and Pritchett 1965). This improved soil environment should favor rapid root development (Haines and Haines 1977).

Wet sites characteristically have a large component of understory and hardwood vegetation. Levels of competing vegetation have not been quantified in most bedding studies. Control of competing vegetation during the site preparation operation has a positive effect on growth of pine. Cain and Mann (1980) found that on sites where hardwoods were controlled loblolly pine volume at age six was 49 percent higher than on untreated areas. They concluded that even though site preparation by chopping allowed establishment of pine, growth was not maximized because of competition from woody and herbaceous vegetation. Stransky (1981) reported that survival, height and diameter growth of loblolly pine was poorest on those sites having the greatest densities of overtopping hardwoods; these sites had received little site preparation. Many other investigators have found that increases in site preparation intensity decrease the amount of competing vegetation in the subsequent pine stand (Haines and Pritchett 1965, Schultz and Wilhite 1974, Schultz 1976).

While some site preparation practices may actually ameliorate the soil, there is increasing concern that certain intensive site preparation operations can negatively modify the soil environment by increasing bulk density and decreasing macropore volume. Stransky (1981) found that soil bulk density increased with increasing intensities of site preparation (table 2), and there was little perceptable recovery of the compacted soils over a three-year period.

Wet, fine-textured soils often receive shear-pile treatments to facilitate subsequent bedding operations. These sites are easily compacted and normally have a narrow time range in which they can be worked with little damage (Terry and Hughes 1975). Shearing and piling operations are potentially the most damaging to soil physical properties because the entire site being treated is traversed by heavy equipment (Terry 1979).

Table 2. Soil bulk densities by site preparation treatment and year from treatment (Stransky 1981).

	Site Preparation Treatment			
Year	Control	Burn	Chop	KG-Shear
	--------- Bulk Density gms/cc ----------			
1	1.29 a*	1.28 a	1.33 b	1.44 b
2	1.26 a	1.27 a	1.33 b	1.36 b

*All values in row followed by same letter are not significantly different at the 5% level.

Little quantitative information exists relating growth performance to both soil physical properties and hardwood competition as affected by site preparation methods. The objectives of this paper are (1) to examine and interpret the growth performance of loblolly pine as related to soil pore space distribution and bulk density and brush competition across three different site preparation treatments in the Interior Flatwoods of Mississippi and (2) to compare soil physical properties under natural loblolly pine stands to that on intensively site-prepared land.

MATERIALS AND METHODS

Data for this investigation were obtained from existing research plots located in the Interior Flatwoods of Kemper County, Mississippi. This resource area is underlain by a deposit of gray, acid shale, known as the Porter's Creek formation, which is relatively impervious to water movement. Consequently, many of the soils become waterlogged for long periods in the winter and spring months. The soils represented in this study are fine-textured, somewhat poorly drained, and of the Falkner (fine-silty, siliceous, thermic Aquic Paleudalf) and Wilcox (fine, montmorillonitic, thermic Vertic Hapludalf) series. While both soils are classified as being somewhat poorly drained, the Wilcox series has poorer internal drainage than the Falkner due to its clayey surface texture. The study site is on an upper slope position with a two to three percent slope which aids in drainage of excess surface water.

The experiment was installed to determine the response of planted loblolly pine to different site preparation techniques. The treatments were:

1. Tree-cruehed (TC) with a Letourneau "tree-crusher"
2. K-G sheared and rootraked-piled (SP)
3. K-G sheared, rootraked-piled, and bedded (SPB)

The study design is a randomized block with four replications. The measurement plots ranged in size from 15.0 m, six rows, wide by approximately 50 m in length in Block I and 7.5 m, three rows, wide by approximately 50 m in length in the remaining blocks.

Height growth on all trees was measured at the end of one, two, three, five, and eight years in the field. Diameter at 1.37 m, DBH, wae measured at the end of eight years in the field. Total wood volume (inside bark) was then calculated using equation [1] (Schmidt and Bower 1970) for trees with both diameter and height measurements and equation [2] (North Carolina State Forest Fertilization Cooperative, 1975) for trees with only height measurements:

$$[1]\ V = [0.03789 + (0.0020911\ ((DBH/2.54)^2\ (H/0.305))]0.028317$$

$$[2]\ V = (0.1153(H/0.305)^{3.191})(1.64 \times 10^{-5})$$

Where : V = Total volume (m^3) inside bark

DBH = Tree diameter (cm) at 1.37 m above soil surface

H = Tree height (m)

At the eight-year measurement, basal area per hectare, height of the tallest 500 trees per hectare, percent survival, and incidence of fusiform rust (Cronartium quercum f. ep. fueiforme) also were determined.

Soil bulk density and pore space distribution were determined from undisturbed cores collected with a 7.6 cm diameter double ring, hammer-driven, core sampler (Blake 1965) (fig. 1). Ten sampling points were randomly located within each measurement plot with one core taken at each sampling point in the 0-7.6 cm depth. Pore space distribution was determined using methods described by Cassel (1974).

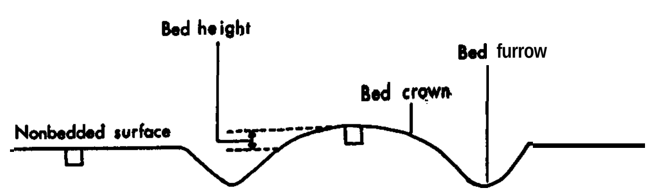

Figure 1. Bed cross-section and sample locations.

Organic matter content was determined by Mississippi State Exteneion Service Soil Testing Lab using a modified colorimetric method (DeBolt 1974).

Data for the competition evaluation were taken within twenty, 8.8 x 10^{-4} hectare, circular subplots located randomly within the measurement plots of each treatment. All woody and pithy stemmed perennials, hereafter referred to as brush competition, were tallied by species and categorized into 2 cm diameter classes within two relative height classes. The two height classes consisted of stems which were less than one-half the average dominant/co-dominant pine height and those which were equal to or greater than this height (Terry and Breedlove 1982). Total brush competition basal area per hectare was then calculated for each diameter-height class.

One way analysis of variance procedures were used to determine if significant differences existed among treatments with regard to pine growth, stand density, fusiform rust incidence, soil physical properties, and hardwood competition. A 0.05 P-test was used for testing overall treatment differences. Duncan's New Multiple Range test was subsequently used to evaluate differences among treatment means when overall treatment differences were significant.

In order to obtain base-line data on height growth and physical properties on a relatively undisturbed Wilcox soil, two natural loblolly pine stands, ages 46 and 43, were studied near the study area. Two dominant sample trees that had been free to grow from an early age as determined by increment boring were selected within a 0.04 hectare circular plot at each site. Selected trees were then felled and annual height growth was determined on each tree using stem analysis. Soil physical properties were determined with the same procedures used on the site-prepared plots. Although the natural stand height growth and soils data cannot be statistically compared to the site preparation study data, they provide useful points of reference .

RESULTS AND DISCUSSION

Stand Characteristics

Significant survival and stocking differences were not observed across the three treatments. The topographic positions where this study is located, an upper slope position with a gentle grade, is conducive to drainage of excess surface water which is beneficial for seedling survival.

Evaluation of the height growth differences among tree crush (TC), sheared and piled (SP), and sheared-piled and bedded (SPB) treatments showed significant pine growth responses to both shearing-piling and the bedding treatments (table 3). Average pine heights on the bedded sites were 1 m or 20 percent greater than on the crushed sites and 0.4 m or 7 percent greater than on the sheared and piled treatment. Height of the tallest 500 trees per hectare showed similar trends with trees on the SPB plots being taller than the TC and SP plots by 16 percent and 5 percent, respectively.

Table 3. Loblolly pine stand characteristics at plantation age eight years by site preparation treatment - Kemper Co., Him., site preparation trial.

Variable		Site Preparation Treatment	
	Tree-Crush	Shear-Pile	Shear-Pile-Bad
Average Height (m) $\bar{x}$	4.9 . *	5.5 b	5.9 c
($S\bar{x}$)	(0.3)	(0.2)	(0.2)
Dominant Height (m)	5.8 .	6.4 b	6.7 b
	(0.4)	(0.2)	(0.2)
DBH (cm)	6.7 .	1.9 b	9.0 c
	(0.5)	(0.4)	(0.2)
BA (m^2/ha)	4.7 •	7.8 b	9.4 b
	(1.0)	(1.0)	(1.2)
Vol. (m^3/ha)	11.5 .	19.3 b	24.0 c
	(1.1)	(1.2)	(1.3)
Survival (%)	72 .	82 .	71 .
	(7.8)	(3.8)	(9.5)
Trees/ha	1268 •	1584 •	1458 a
	(158)	(100)	(126)
Incidence of Bole Cankers (%)	14.9 .	25.8 b	34.0 c
	(1.9)	(3.2)	(3.8)

* Means with the same letter are not significantly different at the 0.05 risk level.

The growth advantages exhibited by the bedded plots were evident at an early age (fig. 2). Height growth differences between treatments still appear to be increasing after eight years. Height growth increments in the age five to eight-year period were 3.7, 3.6, and 3.1 m for the SPB, SP, and TC treatments, respectively. The height growth increment in the natural stands for the same period was 3.3 m; these trees were growing at nearly the same rate as those on the tree-crushed plots.

Whether the bedded sites will continue to express a height growth rate advantage over flat-planted sites on these soils will be answered in time. Wilhite and Jones (1981) found the height growth advantage of a bedded slash pine plantation to decline from 3.3 m to 1.7 m for ages 17 to 35, respectively, when compared to trees on flat-planted sites. Other researchers have observed this decline at earlier ages, e.g., height advantages were disappearing between the fifth and tenth years for slash pine in south Florida (Lennartx and McMinn 1973). However, on poorly drained fine-textured soils in the N. C. Lower Coastal Plain, early pine height growth response gains appear to be maintained at least through age 18 (Hughes et al. 1979).

Average pine diameters were 6.7 cm, 7.9 cm, and 9.0 cm for TC, SP, SPB treatments, respectively (table 3). Pine basal area on bedded plots was twice that on TC plots but not significantly different from the SP treatment.

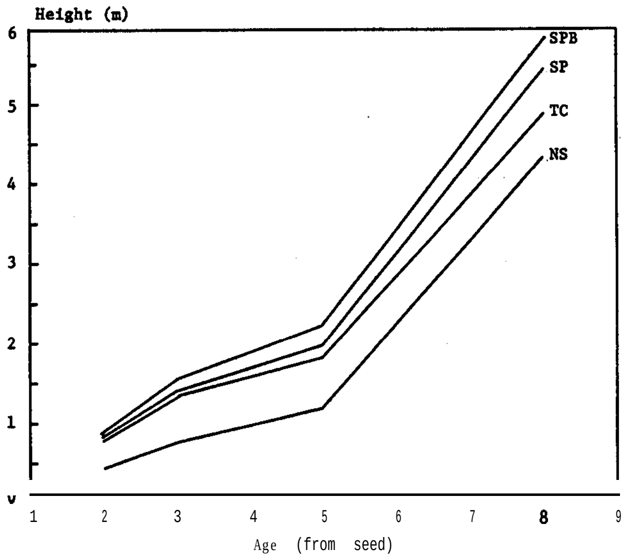

Figure 2. **Loblolly** pine average tree height **as** a function of **age** for shear-pile-bed **(SPB)**. **shear-pile (SP)**, and tree-crushed **(TC)** site prepared plots and adjacent natural stands **(NS)**. Site prepared **areas are** on **Falkner** and Wilcox soils **and** the natural stand is on a Wilcox soil. **Kemper** Co., **Miss.**

The bedding treatment produced the largest total wood volume after eight years in the field. Total pine volume on the bedded plots is currently 110 percent greater than that on the TC plots and 24 percent greater than on the SP treatment (table **3).**

It has been reported that by increasing the early growth rate of pine, the proportion of **trees** infected with fueiform rust can increase substantially **(Derr** and Mann 1977). That observation also is supported by the results of this study; 34 percent of the trees on the SPB treatment have stem cankers, while only 26 percent and 15 percent of the trees were infected on the SP and TC plots, respectively. Most of the infected trees could be removed during the first commercial pulpwood thinning. Because of the growth advantage on the bedded site, the first thinning would occur earlier than on the other treatments and, except for some possible early mortality, the actual pine volume and value loss associated with the relatively high rust infection level on the bedded plots may not be too great. Future monitoring of this study will identify any losses in merchantable pine volume associated with rust infection.

Soil Physical Properties

Soil physical properties were not monitored before the harvest operation or immediately after the site preparation treatments; such data would have defined the effects of logging and site preparation on soil physical properties. Others, however, have found harvesting and site preparation treatment effects to be long lasting (Terry 1978, Switser et al. 1978); therefore, the differences we found likely resulted from the harvest and site preparation treatments.

Shearing and piling increased surface soil bulk density values by 7 percent over TC plots (table 4). This increase was probably caused by the increased contact of the shear and rake tractors with bare mineral soil and some top soil removal during the piling operation. Bedding after the SP operation reduced soil bulk density. The bulk density value on the SP plots probably represents a soil physical condition which does limit growth somewhat. Foil and Ralston (1967) reported a study which demonstrated a trend of reduced seedling growth as soil bulk density increased from 1.0 to 1.4 g/cc. The increased soil bulk density on the SP plots probably represents “moderate” soil damage if a bulk density of 1.4 g/cc is considered to be severe compaction on a fine-textured soil.

Table 4. Soil physical **properties** by treatment **-** **Kemper** Co., **Miss., site** preparation trial.

Soil Variable (0-7.6 cm depth)		Site Preparation Treatment TC	SP	SPB	Natural Stand
Bulk Density (g/cc)	$\bar{x}$ (Sx)	1.19 . * (0.02)	1.27 b (0.03)	1.16 . (0.06)	1.07 (0.02)
Macropore Space **(Vol. %)**		14.2 . (0.4)	13.8 . (0.2)	**18.8** b **(1.5)**	13.6 (1.6)
Micropore Space **(Vol. %)**		38.1 . **(0.8)**	**35.4 a** **(0.8)**	**35.2 a** **(0.9)**	44.6 **(1.7)**
Total Pore space **(Vol. %)**		52.2 . (0.7)	49.3 • (0.6)	54.0 . **(1.8)**	57.9 (1.7)
Organic Matter **(Wt. %)**		**4.69 a** **(0.5)**	3.76 **a** (0.32)	3.05 • **(0.52)**	4.60 **(0.26)**

• **Means with same** letter are **not significantly** different at the 0.05 [illegible] level.

Bedding significantly increased the macropore volume on the bedded sites without decreasing the micropore volume (table 4). This probably occurred by rearranging the strongly developed soil aggregrates into a more porous medium without destroying the aggregrates. In fine-textured soils, large, freely draining macropores are especially important to good drainage and aeration. These conditions in turn are conducive to rapid development of new roots.

Soil bulk density under the natural stand was less than that on the treated sites (table 4). These differences could be partly due to soil textural differences that occur between the two sites. The natural stands had finer textured surface soil than the site preparation study, i.e., clay versus silty clay loam. With the surface textural differences in mind, the soils on the modified sites may not have been dramatically altered by logging or site preparation but some disturbance has occurred as evidenced by the increase in bulk density on the sheared-piled plots. In an intensive forest management operation, more entries and equipent **trafficing** are required on a given land unit to accomplish management **goals.** This fact coupled with shortened rotation ages could have additive detrimental effects on soil physical properties. Some form of soil amelioration, such as disking, ripping or bedding, or combinations of the three, probably will be needed to amend soil physical properties (Moehring 1970).

Brush Competition

Brush competes with pine for both light and moisture during the growing season on these flatwoods sites. While soil moisture levels are high through a portion of the year, it is often very low during the later part of the growing season. Vigorous sprouting occurs on those sites where hardwood root stocks are left intact such as the TC sites. Shearing, piling, and bedding, preferably the latter, eliminate much of this hardwood sprouting problem because root-raking and bedding sever and expose hardwood roots to deseication by sun and wind. In this study the shear and pile treatment reduced hardwood competition proportionally more than the bedding treatment. This probably is due to the rake and pile part of the treatment which scarified the soil surface. Scarification and raking into the soil, however, should be minimieed or eliminated during piling to avoid topsoil removal. Bedding should be able to reduce hardwood competition to acceptable levels. After eight years TC plots had 195 percent more total brush basal area than the SPB plots and 145 percent more brush basal area than the SP treatment (table 5); brush basal area, in fact, exceeded the pine basal area by 19 percent on the TC plots (table 4).

Total basal area of pine and brush was fairly constant among treatments (table 5). The more intensive site preparation treatments appeared to redistribute basal area from brush to pine in almost a 1:1 proportion.

Table 5. Total hardwood basal area in an age eight loblolly pine plantation by site preparation treatment - Kemper Co., Miss. site preparation trial.

	Basal Area (m^2/ha)		
	Site Preparation Treatment		
Component	Tree Crush	Shear-Pile	Shear-Pile-Bed
Pine	4.7 a * (1.0)	7.8 b (1.0)	9.4 b (1.2)
Brush	5.6 a (0.8)	2.3 b (0.6)	1.9 b (0.4)
Total	10.3 (1.3)	10.1 (0.6)	11.3 (1.0)

* Means with the same letter are not significantly different at the 0.05 risk level.

CONCLUSIONS

Identification of site specific factors limiting the growth potential of pine is a prerequisite to developing effective, economically sound site preparation prescriptions. Brush competition was probably the principle factor limiting pine growth on this study site. Total basal area, pine plus brush, was very similar on all treatments. Site preparation noticeably redistributed basal area from brush to pine as site preparation intensity increased from TC to SPB. Incremental gains in tree growth were greater between the SP and TC treatments than between the SP and SPB treatments. The most plausible explanation for this trend is that brush, which wae reduced most by the SP treatment, was limiting pine growth more than the soil physical properties which were modified by bedding. Trees on bedded plots, however, did show a growth advantage over trees on the SP plots and this additional growth gain could be associated with improvement in soil macropore space and additional hardwood control.

One can only speculate what tree growth rates would have been on a chemical site preparation treatment with complete hardwood control or on the TC plots had the hardwoods been removed by burning or chemical means. Disking also could be considered an alternative treatment to bedding on these soils because disking can effectively control hardwoods and should amend soil physical properties.

It could be argued that careful logging debris removal with minimum soil compaction and displacement followed by disking would be preferred treatments on these soils although this combination of treatments was not tested in this study. If a high proportion of a tract was more poorly drained, then bedding may be needed instead of disking. Chemical site preparation treatments also could be proposed as an alternative site preparation treatment since in this case hardwood competition was the factor most limiting growth, but these treatments can not amend soil physical properties and the probability of chemical treatment success is usually less than that with mechanical treatments.

The early pine growth gains exhibited on the more intensively site prepared plots in this study will either be (1) maintained, (2) decreased, or (3) increased through the rotation. Regardless of the growth pattern that finally occurs, the increased early growth on the more intensively prepared sites may represent a significant financial opportunity because of the early age that commercial thinning can be initiated.

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METHODS OF SERICEA LESPEDEZA ESTABLISHMENT FOR FOREST SOIL IMPROVEMENT[1]

Jacques R. Jorgensen and Charles E. Davis[2]

Abstract.--Sericea lespedeza stands for forestry purposes were established by several methods. Stand development was followed over two growing seasons. On soils that ranged from excessively to moderately well-drained, burning was nearly as-effective for stand establishment as was intensive disking. Planting 11.2 kg of seed/ha produced adequate first-year stands. During the second growing season, stands, especially those with few plants, became more dense. Seeding in late winter was more successful than in late spring. Coating seeds improved initial stand establishment and second-year development on severe and moderate sites sown in the winter but had little influence on stands seeded in late spring. Phosphorus fertilization had no influence on first-year establishment or development, but second-year height of plants grown on moderate sites was improved by fertilization.

INTRODUCTION

Forest trees respond to nitrogen (N) application more frequently than to any other fertilizer element, and rising costs for N fertilizers have stimulated interest in biological fixation of N. The majority of N-fixing plants are not adapted to the forest environment[3], but sericea (Lespedeza cuneata (Dum.) G. Don) is an exception. Under forest plantation conditions, it has produced stands dense enough to fix substantial quantities of N (Jorgensen, 1981)[4]. A great deal, however, must be learned about conditions for establishment and management of this valuable species.

In this paper we report research results about quantity of seeds needed to obtain an adequate stand, methods of site preparation, season of sowing, seed coating, application of P fertilizer, and quality of site for pine survival. In our studies, sericea was successfully established on recently logged sites with modest amounts of site preparation. Costs of establishment, competition effects on planted pines, and amounts of N fixed by the established stands are yet to be determined.

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METHODS AND MATERIALS

The experimental areas were located on the Savannah River Project (SRP) south of Aiken, SC, and near Saxapahaw and Troy, NC. Experimental area locations, soil series, the basic site preparation they received, and the severity of the site for tree seedling survival are given in table 1. Soils ranged from excessively well-drained (Lakeland) to moderately well-drained (Yauhannah) and had received site preparation ranging from very intensive windrowing, stumping and disking to burning or no preplanting disturbance of slash and residual vegetation. In most instances site preparation for tree planting preceded planting sericea by several months.

On all areas sowing rates were 5.6, 11.2, and 22.4 kg/ha of live seeds. Seeds were usually sown between late February and early March for the winter season and between mid-April and early May for the spring sowing. At the time of seeding, ground rock phosphate (GRP), triple superphosphate (TSP) or no phosphate was applied to the plots. No other fertilizers or lime were applied. In some experimental areas, preinoculated seeds with a lime coating were sown at one or more rates in addition to uncoated seed. Where equipment was available, soils were lightly disked or raked after seeding and fertilizing to determine the effect covering seeds and incorporating the fertilizer with soil had on stand development. All seeds, except those that were coated and preinoculated were inoculated within a day or two of sowing.

Each area included three replicates in some form of block design. Plots within blocks were usually 6.1 x 6.1 meters. Where seeds were covered with soil by disking with a small tractor, plots were split into disked and undisked segments. If seeds were covered by hand-raking, individual plots were assigned the raking treatment in combination with other treatments and the design was an incomplete randomized block factorial. Seeds were covered on only four areas, all in 1981; three of these areas were on the SRP. Coated seeds were sown on most areas in 1981, but were not used in 1982. Ground rock phosphate was the primary P fertilizer on the SRP experimental areas in 1981. Triple superphosphate was used on other areas in 1981 and on plots sown in 1982.

Sericea populations and height of stands planted in 1981 on the SRP were measured in July or August of 1981 and 1982. Plant numbers and height were tallied in two mechanically located 0.093 m^2 areas in each half plot. Although the presence of more than 10 plants per half plot was noted, we believe that more than 10 seedlings do not enhance stand establishment or development, especially on severe sites. Plants in stands established in 1982 were tallied only once in early August 1982.

Since not all experimental sites received the same treatments, only specific data sets or portions of data sets were used to determine the importance of the experimental factors (table 1).

Table 1.--Experimental area descriptions, treatments and use of data

Soil series	Location[1]	Year seeded	Site preparation	Hazard[2] rating	Treatment[3] applled	Table application
Cecil	Sax.	1981	Windrowing, disking	Moderate	C,F,W.R,S	3
"	"	1982	" "	"	W, R	3
Dothan	SRP	"	Moderate burn	"	F. WS R	2-4
Eustus-Lakeland	"	"	" "	Severe	F: WS: R	2-4
Lakeland	"	1981	Hot burn	"	F,WS,R,S	2-7
"	"	"	Windrowing, disking	"	C,F,WS,R,S	2-7
"	"	"	None	"	F,WS,R,S	3
"	"	"	Windrowing, disking	"	C,F,W, S	7
Lucy	"	1982	Moderate burn	Moderate	F, WS, R	2-4
Orangeburg	"	1981	" "	"	F,WS,R,S	2-7
Orangeburg-Lucy	"	"	Windrowing. disking	"	C,F,WS,R,S	2-7
Orangeburg-Red Bay	"	1982	Moderate burn	"	F. WS. R	2-4
Pinkston	Troy	"	Windrowing, disking	"	W, R	3
Yauhannah	SRP	"	"	"	F, WS, R	2-4

[1]SRP = Savannah River Project, Aiken. SC
Sax. = Saxapahan. NC
Troy = Troy. NC

[2]Hazard rating = degree of expected tree seedling mortality during first two growing seasons

[3]Treatments--may not be complete factorials on each site.
C = Seed covered with soil in some plots
F = Comparison of ground rock phosphate or triple superphosphate. with no fertilizer
WS = Winter and spring plantings
W = Winter planting only
R = Three seeding rates--5.6, 11.2. 22.4 kg/ha

Sites were grouped according to the Soil Conservation Service rating for pine seedling survival into severe and moderate to slight hazard locations. Severe hazard sites, five in all, were droughty Lakeland and Eustis-Lakeland soils low in organic matter. The remaining nine moderate to slight hazard sites, henceforth referred to as moderate, had surface soils that ranged from clayey on one of the Orangeburg sites, to sandy for a site with the Lucy series.

RESULTS

Site Hazard

First-year winter seeding results showed about 25 percent difference, 38.9 vs 28.3 plants/m^2, in favor of the moderate sites (table 2). Spring seeding produced a much lower seedling density: 16.5 plants/m^2 on the moderate vs 11.4 on the severe sites, but the percent difference between the sites was about the same as in the winter sowing. Seedling stocking averaged 67 percent on moderate sites sown in the winter compared to 55 percent on the severe sites. The spring sowing on both sites averaged only 27 percent stocking with no difference due to site severity. On both the moderate and severe sites, the 5.6 kg sowing rate produced fewer plants and had lower stocking than did the two higher rates. The 22.4 kg seeding rate was not clearly superior in number of seedlings or percent stocking to the 11.2 kg seeding rate.

Site Preparation

Type of site preparation influenced the number of plants obtained at each seeding rate (table 3). When seeds were sown on unprepared areas, which contained logging slash as well as a residual forest floor, no significant sericea stand was obtained in the first growing season on severe sites. The few plants that were found were growing where the soil had been bared by harvesting or tree planting. Unfortunately, no moderate completely unprepared sites were available for comparison.

The two major methods of site preparation to reduce competition to newly planted pines, burning and windrowing plus disking, were both effective compared to no preparation in increasing the number of sericea plants. On the severe sites, burning was somewhat inferior to windrowing plus disking, 22.2 vs 38.0 plants/m^2, in promoting establishment. On the moderate sites, however, there were no important differences in the site preparation treatments; burned areas had an average of 33.7 plants/m^2 and windrowed plus disked areas had 40.5. One area of Yauhannah soil that had been windrowed but not disked had a plant density about twice that of other moderate sites. The greater plant density was probably due to the relatively high seasonal water table on the site when seed were sown.

Rate of Sowing

The 5.6 kg sowing rate generally produced fewer plants than the two higher rates (table 3). On the severe sites, there were no differences in the numbers of plants produced by the 11.2 and 22.4 rates, but on the moderate sites seedling density generally increased with seeding rate for all site preparation treatments.

Season of Planting

Season of planting significantly influenced seedling density, and interacted with site quality and year of planting (table 4). Severe and moderate sites planted in the winter had ade-

Table 2. Effect of site quality, season and rate of sowing on sericea density and stocking after the first growing season[1]

Rate of sowing	Seedling density: winter	Seedling density: spring	Seedling stocking: winter	Seedling stocking: spring
kg/ha	---plants/m^2---		----percent----	
		Severe sites		
5.6	19.4	7.7	55	11
11.2	31.9	24.6	67	17
22.4	33.7	[illegible]		56
$\bar{x}$	28.3	11.4	55	28
		Moderate sites		
5.6	22.9	9.2	53	15
11.2	39.8	20.8	71	33
22.4		[illegible]	78	31
$\bar{x}$	54.88.9	19.4 16.5	67	26

[1]Summary of data from nine areas, table 1
[2]Percent of 0.093 m^2 plots with one or more plants

Table L-Effect of site preparation and winter sowing of uncoated sericea seed at three rates on sericea density after the first growing season[1].

Seeding rate	Severe sites: No preparation	Severe sites: Burned	Severe sites: Windrowed disked	Moderate sites: Burned	Moderate sites: Windrowed disked	Moderate sites: Windrowed only
-kg/ha-	---plants/m^2---					
5.6						
11.2	Nos tad	21.5 16.5	54.9 15.1	40.6 17.2	25.6 35.5	63.5 76.4
22.4		28.5	44.1	43.3	60.5	66.2
$\bar{x}$		22.2	36.0	33.7	40.5	76.0

[1]Summary of data from 13 areas, table 1

Table 4.--Influence of planting year, site quality and season of sowing on sericea density and percent of plots stocked with seedlings[1]

Year	Seedling density		Seedling stocking[2]	
	Winter	Spring	Winter	Spring
	--plants/m^2--		----percent----	
	Severe sites			
1981	24.9	16.5	56	41
1982	18.3	0	50	0
	Moderate sites			
1981	42.8	32.0	64	43
1982	35.9	6.3	65	16

[1] Summary of data from nine areas, table 1.
[2] Percent of 0.093 m^2 plots with one or more plants

Table 5.--Effect of site quality, season of sowing, and disking for seedbed preparation and fertilizer incorporation on sericea density over two growing seasons[1]

Site quality	Season of planting	Disked		Not disked	
		First season	Second season	First season	Second season
		plants/m^2			
Moderate	Winter	44.9	72.5	50.0	56.6
	Spring	37.7	56.1	30.4	31.6
Severe	Winter	67.7	65.1	36.4	61.3
	Spring	--	--	11.6	29.7

[1] Summary of data from four areas, table 1

quate plant densities of 18.3 to 42.8 plants/m^2. Plantings made in the winter of 1982 resulted in stands about 80 percent of the density obtained the year before. Spring plantings made in 1982 produced few satisfactory stands. Severe sites had no plants and moderate sites had only 6.3 plants/m^2 whereas in 1981, stocking averaged 24.2 plants/m^2 on both sites. Stocking percent was closely related to the number of plants/m^2.

Seedbed Preparation

Disking for seedbed preparation and fertilizer incorporation on moderate sites resulted in spring sown sericea stands that were only slightly less dense than were stands from winter sowings (table 5). On moderate sites that were not disked, spring sowing produced first-season stand densities that were only about 60 percent of those from the winter plantings. Tallies of stands planted in both seasons on disked moderate sites showed an average density increase of from 41 plants/m^2 the first year to 64 plants/m^2 the second year. On undisked areas with the same treatments there was a small unimportant increase from 40 to 44 plants/m^2.

On severe hazard sites, disking in preparation for winter planting increased first-year density from 36.4 to 57.7 plants/m^2, but the increase in number of plants through the second season was without regard to disking.

Spring sowings on undisked moderate sites showed no increase in the number of plants from the first to second year, but on disked areas the second year population was 149 percent of the first. Undisked severe sites sown in the spring more than doubled plant populations between the first and second growing seasons, increasing from 11.6 to 29.7 plants/m . No sericea stands were established in the spring on severe sites that had been disked for seedbed preparation.

Disking appeared to have a larger overall effect on plant density in the second growing season than in the first (table 5). In winter sowings, there were 43 and 59 plants/m^2 for first and second growing seasons on undisked sites and 51 and 79 on disked sites. Spring sowings on moderate sites produced 30 and 32 plants/m^2 for first and second growing seasons on undisked sites and 38 and 56 on disked areas.

Fertilization

Phosphorus fertilization had little important influence on plant density, percent stocking, or plant height during first year of sericea establishment (table 6). On severe and moderate sites with and without P, there were 41 plants/m^2. Stocking averaged 68 and 79 percent and plant height 21 and 18 cm, respectively, for fertilized and unfertilized plots. By the end of the second growing season, however, fertilized plots averaged 63 plants/m^2 or 52 percent more than after the first season. On unfertilized plots only 49 plants were present, an increase of 20 percent. Second-year percent stocking was not affected by fertilization nor was plant height on the severe site, but fertilized plants on the moderate site averaged 89 cm tall compared to 68 cm for plants on unfertilized plots.

Table 6.--Effect of P fertilization on density, percent stocking, and height over two growing seasons on sericea stands developed by winter sowing 11.2 kg of seed/ha[1]

Fertilizer	Site	Density		Stocking[2]		Height	
		First season	Second season	First season	Second season	First season	Second season
		----plants/m^2----		-----percent-----		------cm------	
P	Severe	42.1	60.4	69	97	18	55
	Moderate	40.4	57.3	67	94	24	89
None	Severe	38.2	48.2	67	94	18	56
	Moderate	44.1	50.6	92	92	17	68

[1] Summary of data from four areas, table 1
[2] Percent of 0.093 m^2 plots with one or more plants

Seed Coating

The use of coated seeds, had an important positive influence on sericea density in winter sowings on both severe and moderate sites (table 7). At the end of the first season, on these areas, there were 52 plants/m^2 derived from coated seed and only 40 from uncoated seed, with similar increases due to coating on both sites. During the second season on the two sites, the number of plants derived from uncoated seed increased by about 9 to 49/m^2, but when coated seed were used, the number increased by 19 to 71 plants/m^2. The majority of increase from both types of seed occurred on the severe site. Density on the moderate site remained about the same. When seed were sown in the spring there was no overall difference due to coating at the first or second growing season. Most of these data were extremely variable, but it is believed variation is due to experimental error rather than to any treatment effects.

Table 7.--Effect of seeding rate, seed coating, site quality, and season of sowing on sericea density over two growing seasons[1]

Rate of seeding	Seed coating	Severe sites: First season	Severe sites: Second season	Moderate sites: First season	Moderate sites: Second season	All sites: First season	All sites: Second season
		-----------	-----------	plants/m^2	-----------	-----------	-----------
				Winter sowing			
5.6	+[2]	35.0	74.2	46.4	44.6		
	-[3]	21.0	26.4	14.6	26.5		
11.2	+	46.0	60.7	35.2	64.6		
	-	36.2	54.6	50.5	50.0		
22.4	+	62.1	61.6	68.1	62.3		
		47.0	65.3	61.0	70.5		
$\bar{x}$	+	47.7	78.8	51.2	63.8	52.4	71.3
		35.4	48.8	44.3	49.7	39.8	49.2
			Spring	solving			
				19.4			
5.6	+	11.4	17.6	21.6	44.6		
			32.0		21.4		
		2.7		[illegible]	24.5		
11.2	+	9.7	20.5	31.7	30.1		
		6.4	36.0	68.8	50.0		
22.4	+	8.1	46.6	38.8	29.6	24.0	
$\bar{x}$	+	16.4	26.7	40.0	39.7	23.0	33.2
			32.4	29.5	29.0		30.7

[1] Summary of data from five areas, table 1
[2] + = coated seed
[3] - = uncoated seed

DISCUSSION

Good stands of sericea lespedeza can be established at seeding rates as low as 5.6 kg of seed/ha. This rate is only about an eighth of that recommended for agronomic use. Since plants are harvested during the first year in an agronomic stand, initial plant development and seed production are limited and a dense initial stand is required, In forestry, plants may develop and produce seeds during the first season and have only minor harvesting by wildlife. Thus, effective stands of sericea for forest management may be less than fully stocked at the end of the first growing season and still completely occupy the site by the end of the second growing season.

Areas sown in the winter with 5.6 kg of seed/ha had approximately 20 plants/m^2 at the end of the first season and were predicted to have 37 plants by the end of the second. This second-year population is believed sufficient to produce the biomass needed to support an important amount of N fixation and to compete with other vegetation. However, many sites sown with 5.6 kg of seed will have fewer than 10-15 plants/m^2 and some insurance for good stands may be had by increasing the sowing rate to 11 kg of seed/ha. Any heavier sowing will not generally result in a denser stand at the end of the second growing season. Sericea stands that are established at low seeding rates, may be more sensitive to an adverse environment--drought, competition, browsing--than will somewhat denser stands that develop from higher seeding rates.

A major precaution to be taken for assurance of successful sericea establishment is to sow seed in late winter. Seeds sown during this period are more likely to have sufficient moisture for germination and the young plants have more time for development to resist summer droughts than will spring sown plants. Seeds sown in April or May produced only half the plant density as earlier sowings. This reduction in initial density was followed by fewer plants at the end of the second growing season compared to stands established from winter sowings.

Over the P-year test period reasonably uniform sericea establishment was achieved on moderate and severe sites by sowing in the winter. Spring sowings were satisfactory in 1981, but failed in 1982. Undoubtedly, if there is a choice between early and late sowing, early sowing is preferred. If early sowing cannot be done, is it better to sow late or wait until the following year? There is no documented answer at this time.

Some site preparation is necessary to establish a sericea stand and carry it through to the end of the first growing season. Seeds sown on areas without any preparation failed to produce significant stands of plants. The preparation need not be extensive; burning is sufficient. Stands on burned areas tended to be less dense than those on windrowed and disked areas, especially on severe sites, but on moderate sites the difference in stand density due to preparation method was small.

Disking to prepare seedbeds and to incorporate fertilizer is an effective method' of increasing stand density the first year. During the second growing season, in most instances, stands on disked and undisked areas developed at the same rate. Thus, the most costly aspect of sericea establishment, separate seedbed preparation, is unnecessary or may in part be replaced by sowing somewhat more than the minimum amount of seed.

Fertilization with P had no effect on stand establishment and only influenced height of stands on moderate sites during the second growing season. This result may not be unusual for the SRP area, since much of it was farmland that was taken out of agriculture about 30 years ago. Residual P, in the soil from crop fertilization, apparently was sufficient for sericeas' initial growth and enabled it to compete with weeds. Although plant density was not influenced by fertilization, stand height on moderate sites was. Stand height is usually related to biomass and this to the plants' capacity to fix N. Thus, larger plants on fertilized sites are capable of more N fixation than are an equal number of smaller plants on unfertilized areas. In the Lower Coastal Plain of North Carolina on low-P, nonagricultural soils, sericea established without P fertilization was practically eliminated by native weed competition 4 years after establishment, and even at age 2, stands were poor compared to those receiving P fertilizer (Jorgensen 1981).

Seed coating improved both initial and second-growing-season stands derived from winter sowing on both severe and moderate sites. However, coated seed showed no overall advantage when sown in the spring. Whether or not coated seed should be used will depend on cost and ease of seed placement, especially if large areas are to be sown from the air.

CONCLUSIONS

Sericea stands can be successfully established on unfertile, acid forest soils by:

1. Preparing the site prior to planting by burning or other procedures which will expose mineral soil.

2. Sowing hulled, scarified, inoculated sericea seeds at a minimum rate of 5.6 kg and maximum of 11.2 kg of live seed/ha.

3. Sowing seeds in late winter, after severe cold weather has passed (sericea seedlings are cold-tolerant).

4. Applying approximately 50 kg of P/ha for stand maintenance and development on sites that are low in available P.

SOIL RESPONSE TO CLEARCUTTING AND SITE PREPARATION IN EAST TEXAS[1]

J. J. Stransky, L. K. Halls, and K. G. Watterston[2]

Abstract.-- On an east Texas forest site, clearcutting and site preparation did not change the soil pH. Chopping and KG blading significantly reduced organic matter in the surface soil, while burning slightly increased it. Organic matter showed a positive and significant relationship to potassium, calcium and magnesium. All site treatments increased phosphorus and potassium, with the greatest increase on the burned plots. Calcium and magnesium contents also increased with burning but decreased with KG blading. Burning appeared better than the other treatments for maintaining or improving the soil nutrient regime. However, planted loblolly pine seedlings survived and grew best with mechanical treatments that controlled competing vegetation.

INTRODUCTION

For fifty years clearcutting has been a serious issue among forest managers. In the late twenties and early thirties, many European foresters expressed concern about the effects of clearcutting on the soil. Wittich (1930) found no biological changes in the soil after clearcutting in Germany and attributed temporary changes in the nutrient regime to the transition from one plant successional stage to another, Fehèr (1931) in Hungary supported Wittich's findings that the effects of clearcutting are short-lived and are reversed by the beneficial shading of upcoming vegetation.

The clearcutting issue became more complicated with the addition of questions about its unsightliness and loss of wildlife habitat. But the current controversy centers largely on loss of soil productivity. As a result, court decisions have banned clearcutting in many parts of the United States. Facts are needed to clarify some of the misunderstandings between proponents and opponents of clearcutting and site preparation. Recent studies in New Hampshire and in the central and southern Appalachians indicated relatively little adverse effects from clearcutting on soil nutrients (Reinhart 1973).

OBJECTIVE

The objective of this study was to determine soil response to timber clearcutting and the preparation of planting sites in the loblolly-shortleaf pine-hardwood forest type that covers nearly 70 million ac in the South and reaches its westernmost extension in east Texas.

STUDY SITE

The study site was located on a nearly level to gently sloping terrace on the Angelina River in Jasper County, Texas. The tract, owned by Temple-Eastex, Incorporated, had never been cleared for agricultural crops, although it was probably grazed by livestock in the past (Stransky 1976).

The area is part of the Gulf Coastal Plain's Quaternary deposits, which are underlain by sands, sandstones, and clays of the Tertiary's Oligocene period (Dumble 1918).

Soils belong to the Bernaldo-Elysian complex and to the Sacul series. Bernaldo-Elysian soils are moundy and occur in such a complex pattern that separation is very difficult. Bernaldo soils (Glossic Paleudalfs, fine-loamy siliceous) occupy the lower part of the mounds and most of the

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The study was established and is maintained with the assistance of Temple-Eastex, Incorporated of Jasper, Texas.

adjoining low areas, and compose about 50 percent of the mapped areas. Elysian soils (Haplic Glossudalfs, coarse-loamy, siliceous) occupy most of the large mounds and compose about 40 percent of the area. The major difference between these soils is that the sandy surface layer is more than 20 inches thick on the Elysian soil, but is thinner on the Bernaldo. Slopes of both soils range from 0 to 3 percent. These are well drained, moderately permeable soils that have slow runoff.

Sacul soils (Aquic Hapludalfs, clayey, mixed) occur at the head of drains and normally have a concave topography. They occupy slopes from 1 to 6 percent, are moderately well drained, and have slow permeability.

Summers are hot and humid, and the winters mild. The growing season is about 240 days long. Annual rainfall averages about 51 inches, but in 1972, 1973, and 1974 it was 54, 87, and 70 inches; often interfering with planned study activities.

On the experimental site, loblolly pine (*Pinus taeda* L.) and some shortleaf pine (*Pinus echinata* Mill.) occurred in admixture with southern red oak (*Quercus falcata* Michx.), post oak (*Quercus stellata* Wang.), water oak (*Quercus nigra* L.), sweetgum (*Liquidambar styraciflua* L.), and blackgum (*Nvssa svlvatica* Marsh.).

Prominent shrubs were American beautyberry (*Callicarpa americana* L.), yaupon (*Ilex vomitoria* Ait.), blackberry (*Rubus* spp.), and southern waxmyrtle (*Myrica cerifera* L.). Carolina jessamine (*Gelsemium sempervirens* (L.) Ait. f.), muscadine grape (*Vitis rotundifolia* Michx.), and greenbriers (*Smilax* spp.) were the most prominent vines.

Longleaf uniola (*Uniola sessiliflora* Poir.), devils's grandmother (*Elephantopus tomentosus* L.), and two-eyed-berry (*Mitchella repens* L.) were the most abundant herbaceous plants.

STUDY METHODS

Design and Treatments

In September 1972 all the merchantable trees were cut and removed from the study area. During February and March 1974 the following site preparation treatments were applied to 1 1/2 ac plots in a randomized block design with unequal replications:

Control--No site preparation, all woody stems greater than 1 inch in diameter at breast-height (d.b.h.) were cut.
Burn--all stems greater than 1 inch d.b.h. were cut and burned with the logging slash. Fanned by a steady wind of about 12 miles per hour, the head fire consumed the tops of all herbaceous plants, most shrubs and small trees, nearly all the leaf litter, and all but the large branches of the logging slash.
Chop--logging slash and all stems were cut with a chopper and burned, The chopper resembles a huge lawn roller equipped with cutting blades parallel to the long axis of the cylinder. Pulled by a large crawler tractor, the chopper cut non-merchantable trees and shrubs into small chunks and crushed the debris into the surface soil. The chopped plots have been prepared in October 1972, but heavy rains prevented completion of the other treatments. These plots were rechopped when the other site treatments were applied.
KG--all stems were cut with a KG blade, and the logging slash was raked off the plots and burned. The KG blade resembles a straight razor and is mounted at an angle on the front of a tractor. It sheared off all stems in its path. The cutting process greatly churned up the soil surface and pushed some litter and topsoil off the planting site.

The area was handplanted with 1-0 loblolly pine seedlings at 8 x 10 foot spacing in mid-March 1974.

Soil Response Measurements

In August 1972 (before clearcutting) and in December 1974 (one growing season after site treatments were applied) five 1 inch diameter soil cores were taken at the depth of 0 to 2 and 2 to 5 inches near each of 20 sample points that were established in the interior 1 ac center of each plot. The five individual samples from each depth were composited and analyzed for organic matter by loss on ignition, pH by glass electrode, phosphorus by the sulfomolybdic blue color method, and potassium, calcium, and magnesium by the atomic absorption method.

The 1972 and 1974 data were compared by analysis of variance. All testing was at the 0.05 percent level of significance. The Bernaldo-Elysian and the Sacul soils were combined and considered as one soil because initially (1972) neither forage yield nor most surface soil characteristics were significantly different between the two soil types.

RESULTS AND DISCUSSION

Clearcutting itself probably did not remove sizeable amounts of nutrients as only the logs were taken from the area. The upper stems and crowns with their branches, twigs, and foliage were left on the ground to be incorporated into the soil by decay, fire, or chopping. Nutrient losses from this type of logging are small because the logs contain few nutrients, and most are in the leaves and twigs (Stone 1973). Some leaching of soil nutrients could occur after clearcutting, but rapid revegetation usually protects the soil surface and continues to add nutrients (Burns and Hebb 1972, Stransky et al. 1974).

PH

Soil pH values were similar for all treatments and at both soil depths before and after site preparation (Table 1). This result is somewhat in contrast to another study that shows small increases in pH by burning (Wells 1971).

Organic Matter

In both 1972 and 1974, organic matter was about two times higher in the surface soil than in the 2 to 5 inch depth (Table 1). Differences between plots were not significant in 1972, but in 1974 the soil on the chopped and KG plots had significantly less organic matter content in the surface soil than the control and burned plots.

Several studies have described the positive relationship between fertility and organic matter content of southern forest soils. Stransky (1961, 1964) showed that the growth of planted pine seedlings was retarded by organic matter removal. Thus, the decreased organic matter on the chopped and KG plots can possibly influence the future productivity of the site. The effects of litter and slash removal are likely to be most pronounced where hardwoods predominate because the hardwood litter contains more nutrients and decomposes faster than pine litter (Alway et al. 1933, Coile 1937).

The explanation for the lowered organic matter content on the KG plots is fairly obvious. The organic matter was simply removed from the plots. Haines et al. (1975) warned that such practices would be detrimental to the soil nutrient regime, and Hicock et al. (1931) noted that the removal of litter alone would seriously deplete organic matter reserves.

The losses with chopping are difficult to explain as no organic matter was removed from the plots. The slash was broken up by repeated chopping and pressed into the soil surface, possibly resulting in more rapid decay. Because of heavy rains in 1973 and 1974, some of it could have been washed from the ridges into the valleys cut by the chopper blades. As only the ridges were sampled, some of the organic matter may have been excluded. It is unlikely that the organic matter moved to lower soil depths as the 2 to 5 inch depth showed no increase.

phosphorus

Before clearcutting, the soils had a higher phosphorus content in tha surface layer than in the 2 to 5 inch depth. After the timber was cut and the sites prepared, however, the differences between depths became non-significant (Table 1). In this study it appeared that phosphorus increased in the lower depth as a result of leaching from the surface.

Table 1.-- Soil characteristics before clearcutting (1972) and after site preparation (1974).

Soil Characteriatice	Soil Depth (in)	Control 1972	Control 1974	Burn 1972	Burn 1974	Chop 1972	Chop 1974	KG 1972	KG 1974
pH	o-2	5.3	5.3	5.4	5.5	5.6	5.6	5.2	5.4
	2-5	5.3	5.3	5.5	5.5	5.7	5.6	5.3	5.4
Organic Matter (percent)	O-2	5.8	5.2	5.3	5.6	5.7	4.4	6.0	3.6
	2-5	2.8	2.5	2.4	2.6	2.7	2.6	3.0	2.0
Phosphorus (ppm)	O-2	6.5	5.2	5.4	6.4	4.0	4.4	4.7	5.5
	2-5	3.7	4.6	3.5	4.6	1.9	4.0	2.0	5.8
Potassium (ppm)	o-2	39.3	39.9	30.7	38.9	30.8	34.2	31.2	34.2
	2-5	16.3	19.7	16.9	la.4	la.9	19.4	17.5	la.7
Calcium (ppm)	o-2	243.6	286.4	180.6	232.4		227.0	157.2	145.3
	2-5	85.4	84.3	65.1	67.0	232.7 99.7	87.7	46.9	46.0
Magnesium (ppm)	O-2	65.2	50.8	51.6	54.8	42.6	43.8	49.9	38.0
	2-5	41.0	27.9	22.0	19.9	17.1	19.7	22.0	22.0

In 1972, the plots to be chopped and KG **bladed** were significantly lower in phosphorus than the control and burn plots, but the reason why was not **obvious.** In 1974, phosphorus had increased on all **treatments** except the control, and treatment differences were still significant. The greatest **increase** in phosphorus occurred on the burned Plots, probably because of the phosphorus released in burning. The interactions of depth x treatments were not significant in either 1972 or 1974.

Potassium

Potassium content of the soil was consistently higher in the surface than in the 2 to 5 inch depth (Table 1). For an as yet unknown reason it was higher, too, in the surface soil of the control plots than on the other plots in 1972. After site preparation the treatment differences were no longer significant. **This** difference in potassium between years was significant in the surface soil, but not in the 2 to 5 inch depth, indicating greater increases in the surface between years. The depth x treatment interaction was non-significant in both years.

Calcium

Calcium content was significantly greater in the surface soil than in the 2 to 5 inch depth in both 1972 and 1974 (Table 1). Calcium contents at both **soil** depths were not significantly different between plots before cutting and site treatments. However, differences in calcium levels between treatments were significant for the surface soil layer in 1974 as a result of increases **on** the control and burned plots and slight decreases on the chopped and KG bladed plots.

Magnesium

Magnesium content was approximately two times higher in the surface soil than in the 2 to 5 inch depth (Table 1). In 1972, **magnesium content** was significantly higher on the control plots than on any others. In 1974, the KG bladed plots had the lowest content of magnesium in the Surface soil, probably because raking the logging slash off the plots removed organic matter.

Nutrient Relationships

Simple linear regressions indicated that organic matter was significantly related to calcium, magnesium, and **potassium** content of the soil. Other studies have also shown the close **relationship** between organic matter and **mineral** content of coarse-textured soils (Wilde 1946). The increase of phosphorus, potassium, calcium, and magnesium in the 0 to 2 inch layer of soil corroborates studies which indicate that fire benefits the soil nutrient regime in southern upland forests (Moehring et al. 1966, Stone 1971, **Wells** 1971).

However, despite of their generally lower nutrient regime and higher soil bulk density (Stransky **1981),** the planted pines survived and grew best on the mechanically prepared sites where competing vegetation was effectively reduced (Stransky and Halls 1981).

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INTENSIVE WHOLE-TREE HARVESTING AS A SITE PREPARATION TECHNIQUE[1/]

James W. McMinn[2/]

Abstract.--Whole-tree harvesting for fuel chips can create better site conditions for regenerating desirable species than does clearcutting for conventional wood products. In mixed hardwood-pine stands of the Upper Piedmont, all woody biomass was removed down to l-inch or 4-inch diameter limits in both winter and summer. The l-inch limit harvest exposed twice as much mineral soil area as the O-inch limit harvest in both seasons, and the winter harvest exposed 16 percent more mineral soil than the summer harvest at both intensities. Hardwood sprouting was most prolific after the l-inch winter harvest and least prolific after the 4-inch summer harvest. Adequate stocking of pine seedlings was obtained by the seeds-in-place technique after the winter harvest.

INTRODUCTION

During the past three decades the cost of site preparation has increased more than the cost of any other widespread forestry practice in the South. The increase averaged 11.9 percent annually for the period 1952-1979, while the annual increase in the wholesale price index was 3.2 percent (Moak 1982). This increasing real cost coincided with a growing formal recognition that more preparation will be required to maintain southern forestlands in a commercially productive state (Boyce and McClure 1975, Society of American Foresters 1979). Whole-tree chipping for fuel could eliminate this dilemma. Fuel chip production is economically feasible because it permits removal of so much more material than conventional harvesting and it has the potential for reducing or eliminating the need for site preparation (Butts and Preston 1979). McGee (1980) found in a study on the Cumberland Plateau that whole-tree harvesting of all material 4 inches and larger could be followed by successful pine planting or desirable hardwood sprout regeneration, although further site preparation or release might be necessary. Four inches is a generally accepted lower limit for fuelwood harvesting, but even smaller limits might be practical if better site preparation were effected.

The objective of the work reported here was to compare the effects of season and intensity of whole-tree harvesting in mixed hardwood-pine stands of the Upper Piedmont on the site and the subsequent stand. This is one phase of a broader study with several objectives, including the effects on site productivity (McMinn and Nutter 1981, McNab and McMinn 1982). Mineral soil exposure and hardwood sprout regrowth were used as indices of site preparation success. Exposed soil and minimal sprout growth favor regeneration of pines (Langdon 1981) and relatively intolerant hardwoods (Smith 1980) that are more desirable than the tolerant hardwoods dominating the upland sites studied.

METHODS

The study was conducted on the Dawson Forest, located in the Upper Piedmont of Georgia NNE of Atlanta, and managed by the Georgia Forestry Commission. Soils are Fannin fine sandy loam and Tallapoosa fine sandy loam. The site reverted to forest following agricultural abandonment early in the century. Prior to the relatively recent control by the Commission, the timber stands on this site had been high-graded for both pine and hardwood, leaving stands with insufficient merchantable volumes for profitable conventional logging. The hardwood component was comprised primarily of chestnut oak (*Quercus prinus* L.), northern red oak (*Q. rubra* L.), post oak (*Q. stellata* Wangenh.), scarlet oak (*Q. coccinea* Muenchh.), southern red oak (*Q. falcata* Michx.), and hickory (*Carya* spp.). The pine component was primarily loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.). Basal area averaged approximately 100 square feet per acre, of which about 65 percent was hard hardwood, 10 percent soft hardwood, and 25 percent was pine. Diameters ranged from 1 to 20 inches for hard hardwoods, 1 to 16 inches for soft hardwoods, and 1 to 14 inches for pine. There were approximately 980 stems per acre for all species combined. Nearly 80 percent of these stems were smaller than 4.5 inches d.b.h. but this component accounted for only 26 percent of the total basal area per acre.

Georgia Forestry Commission crews accomplished the harvesting treatments with a typical whole-tree

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system comprised of small feller-bunchers, **grapple-skidders**, and an **18-inch** disk-type chipper. Harvesting was done to **4-inch** or l-inch d.b.h. limits in both winter and **summer.** Harvesting was completed in January and June of 1980. Each combination of season and intensity was replicated three times in a completely randomized design. Logging plots were 1 acre in size, and detailed observations and sampling were confined to the interior half-acre of each plot. The most intensive harvest yielded from about 67 to 83 green tons per acre and the least intensive approximately 20 percent less.

Logging disturbance was estimated on a **180-**point grid on each plot. The grid consisted of a point every 2 feet along three line transects bisecting the measurement plots at quarter-, half-, and three-quarter intervals. Each point was classified either as (1) undisturbed, (2) mineral soil exposed but not scarified, or (3) soil scarified. Analysis of variance was performed on **arcsine** transformations of the percentage of points falling in the last category and the last two categories combined. Sprout regrowth was characterized by a 100 percent inventory of sprout **clumps** in October of 1981. Height of the tallest sprout and average diameter at the widest horizontal spread were recorded for each clump. Both mean sprout height **per** plot and sprout coverage per acre, based on vertical projections of clump diameter, were subjected to analysis of variance. In April 1981 milacre plots at IO-foot intervals along the line transects were examined for pine seedling stocking.

RESULTS AND DISCUSSION

There was no significant difference among treatments in the percent area scarified (table 1). Overall, approximately 16 percent of the area was scarified, and treatment means ranged only from 13 to 19 percent. There were, however, significant differences both due to season and intensity in the area of mineral soil exposed by the logging (table 2). There was twice as much soil exposure in plots harvested to a l-inch limit as in plots harvested to a 4-inch limit in both winter end **summer.** Pine seedling stocking in April 1981 was significantly influenced by harvest intensity. After winter logging to a l-inch limit, 94 percent of the milacres were stocked with natural pine regeneration, whereas harvesting to a 4-inch limit resulted in 62 percent stocking (which is still adequate by most standards). This finding is consistent with Pomeroy's (1949) conclusion that a mineral soil **seedbed** substantially enhances loblolly seedling establishment. **Logging** in winter, when conditions were and normally are wetter than in summer, resulted in approximately 15 percent more soil exposure than summer logging at both harvest intensities. No natural pine regeneration occurred after the summer logging, because in this study pine regeneration depended on the **"seeds-**in-place" technique described by Lotti (1961). The technique consists of removing a mature stand from which adequate viable seeds have recently fallen.

Areal coverage of sprout regrowth was significantly affected by both season and intensity of harvesting (table 3). Sprout coverage averaged almost **70** percent greater on winter- than on summer-logged plots. Part of this difference may

Table 1.--Summary of analysis of variance results (**-statistically significant at the **.01** level, &statistically significant at the **.05** level, **NS=nonsignificant)**

Source of variation	Soil: Exposure	Soil: Scarification	Sprouting: Coverage	Sprouting: Height
Season	*	NS	*	*
Intensity	**	NS	*	NS
S X I	NS	NS	NS	NS

Table 2.--Percent area over which mineral soil was exposed by season and intensity of whole-tree harvesting (standard deviations in parentheses)

Diameter limit (inches)	Season: Winter	Season: Summer	Mean
	- - - e - - *-Percent-* - - - - - -		
4	**34.7(5.1)**	**30.3(7.1)**	32.5
1	**70.7(3.5)**	**61.0(3.0)**	65.8
Mean	52.7	45.6	

Table 3.--Sprout coverage per acre by season and intensity of whole-tree harvesting (standard deviations in parentheses)

Diameter limit (inches)	Season: Winter	Season: Summer	Mean
	- - - - - - - *Ft^2/acre* - - - - - - -		
4	**3985**(715)	**2046**(653)	3016
1	**6175(2490)**	**3996(1336)**	5086
Mean	5080	3021	

be attributed to the two full seasons of regrowth on the winter treatment and only **one-and-a-half** seasons on the summer treatment. However, it is unlikely that all of the disparity was because of the fractional difference in growing seasons, and observations **will** be made during the next few years to determine if this relationship holds over time. **Belanger** (1979) reported that coppice growth of sycamore ***(Platanusoccidentalis*** L.) in the Georgia Piedmont was more prolific after winter harvesting than after summer harvesting.

Harvest intensity also had a significant effect on sprout coverage. The l-inch limit resulted in **1-1/2** times the coverage of the **4-inch** limit after winter logging and almost twice the coverage after summer logging. Sprouting of small stumps contributed little to areal coverage on the most intensively logged treatments. Therefore, the difference by logging intensity was attributed primarily to competition from the residual stand of small stems. Since this competition will likely affect intolerant seedlings more than sprouts, pine seedling stocking is expected to decline on the 4-inch limit treatment.

Mean sprout height varied little among treatments (table 4); sprouts after winter logging were slightly but significantly taller than those after summer logging. This difference was less than 10 percent, and it is attributed to the fractional difference in growing seasons between treatments.

Table 4.--Mean sprout height by season and intensity of whole-tree harvesting (standard deviations of mean plot values in parentheses)

Diameter limit (inches)	Season		
	Winter	Summer	Mean
	- - - - - - -	- - - - - - - -	
4	**6.3(.2)**	**5.9(.3)**	6.1
1	**6.2(.3)**	**5.7(.3)**	6.0
Mean	6.3	5.8	

CONCLUSIONS

Although additional observations will be required to assess the need for reducing competition, the site preparation effects are evident after 2 years. Site preparation on Upper Piedmont soils is substantially better when whole-tree harvesting is done to a l-inch limit rather than a 4-inch limit. This improvement in site preparation is needed for intolerant species requiring a mineral soil **seedbed.** Harvesting to a l-inch limit during winters following an adequate pine seed crop provides a good chance for successful natural regeneration. However, if the prescription involves direct seeding or planting, a summer harvest to a l-inch limit is recommended because harvesting during that period tends to minimize regrowth of competing stump sprouts.

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GROWTH OF YOUNG LONGLEAF PINE AS AFFECTED BY BIENNIAL BURNS PLUS CHEMICAL OR MECHANICAL TREATMENTS FOR COMPETITION CONTROL[1]

William O. Boyer[2]

Abstract.--A study of the effects of understory control treatments on the growth of sapling longleaf pine was begun in 1973. Four burning treatments were combined with each of three supplemental treatments. After 7 years, pine growth was not improved by cultural treatments. Growth was significantly better on unburned than burned plots, while supplemental treatments had no effect.

INTRODUCTION

Competing understory vegetation, particularly hardwoods and other woody plant species, deters optimum growth of overstory pine, especially at young ages. Controlling this competition is the principal objective of most cultural treatments. These include (1) mechanical treatments, usually applied to prepare the site before regeneration, (2) herbicides, which may be applied for site preparation or to release pines from competition and (3) prescribed fire which, if regularly applied, can prevent or retard the encroachment of hardwoods into pine stands. Except for fire, these treatments are expensive, but their cost is justified through expected increases in volume yields.

Pines have responded with improved growth to reduction or elimination of understory hardwoods, according to a number of reports. This positive response covers a range of sizes or ages that include loblolly pines under age 10 (Cain and Mann 1980, Clason 19781, sapling loblolly, shortleaf, and longleaf (Loyd et al. 1978) and also pole to sawlog size loblolly and shortleaf pines (Bower and Ferguson 1968, Grano 1970). Positive growth responses are not always observed. Removal of more than 3,800 hardwood understory stems did not improve growth of pole-sized loblolly pine (Russell 1961).

Longleaf pine appears to be more sensitive to competition than other pines. Elimination of understory hardwoods should promote a positive growth response in longleaf at least as great as that observed in other pines. Little information is available on longleaf growth response to competition control beyond the seedling stage. Treatment of grass-stage longleaf stands with 2,4,5-T applied from the air resulted in greater average height and 40 percent more merchantable volume after 20 years than similar untreated stands (Michael 1980). Whether this growth differential resulted from earlier initiation of height growth by treated stands, or better growth through the entire period, or both, is unknown.

A study was initiated in 1973 on the Escambia Experimental Forest in South Alabama to determine the effects of repeated understory competition control treatments on understory structure and biomass, and growth of a 12-year-old longleaf pine overstory.

METHODS

The study is located on sandy upland soils of the middle coastal plain. The predominant soil series in all study blocks is Troup although some Wagram and Dothan soils are also present.

Three study blocks, each comprised of 12 square 0.4-acre plots, were established in relatively uniform, even-aged stands of young longleaf pine. A 0.1 acre net plot was centered in each 0.4-acre treatment plot. The stands originated from the 1958 seed crop and were released from the parent overstory during the

[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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winter of 1961. Dated from overstory removal., stands were I2 Years old at study establishment in 1973. All plots were thinned to 500 dominant Pines Per acre, and 50 pines in each 0.1-acre net Plot were numbered, and total height and diameter at breast height (d.b.h.) recorded. Individual tree inside bark total cubic foot volume was obtained from height and d.b.h. using a longleaf Pine volume table (Farrar 1981). At age 12, Pines averaged 3.2 inches d.b.h., 22.6 feet in total height, with a density of 30.1 ft^2 basal area/acre.

Twelve treatment combinations were randomly assigned among the 12 plots in each block. Four burning treatments include prescribed fire at two-year intervals in winter, spring, Sumner and unburned check. Combined with each burning treatment were three supplemental treatments. These were chemical treatment of all woody stems with 2,4-D at time of study establishment, handclearing of all woody vegetation 4.5 feet or more in height at beginning of the study and at P-year intervals thereafter, and an untreated check.

At study establishment, and before treatment, the composition and structure of understory vegetation was sampled on 9 (3.1-foot square) subplots in each net plot. The number of stems and species of all woody plants were recorded, as well as dry weights of all woody plants less than 0.5-inch in diameter at 6 inches above ground. Dry weights were also obtained for grasses and grass likes, legumes, forbs, and surface litter (all dead organic material above mineral soil).

Fines in net plots were remeasured during the winter of 1980. In addition, all hardwoods on each net plot in the 2-inch d.b.h. class and larger (1.5" d.b.h.) were inventoried, and d.b.h. and species recorded. Understory vegetation (woody and herbaceous) and litter were sampled on 9 subplots per plot, as before. Number of woody stems per subplot was recorded, by species, in two groups: Those above 0.5-inch in diameter at 6 inches above ground to 1.5-inches d.b.h., and those 0.5-inch in diameter or less. The latter were both counted and harvested for dry weight determination.

Analysis of variance was used to determine treatment effects on understory conditions and pine growth.

RESULTS

pine growth was not improved by any of the cultural treatments. To the contrary, pine height, diameter and volume growth were Significantly better on unburned plots than on any of the burning treatments. Supplemental treatments had no significant effect on any measure of growth.

Height growth over the 7-year period averaged 19 feet on unburned plots, and 17 feet for each of the burning treatments. Annual d.b.h. growth averaged 0.219" on unburned plots, and ranged from 0.187" to 0.196" for the three burning treatments, and 0.193" to 0.207" for supplemental treatments. Annual per acre volume growth (Table 1) averaged 125 ft^3 for the no-burn treatments compared with 96 to 103 ft^3 for

Table 1.--Understory treatment and average annual volume growth of overstory pine over 7 years

Supplemental Treatment	Season of Biennial Burn: Winter	Spring	Summer	None	Average
	---------- u 1C ee acre --------				
Chemical	94	91	190	118	109a
Hand Clearing	99	104	65	134	107a
None	111	113		125	104a
Average	102a[1/]	103a	96a	125b	107

1/ Column or row means followed by the same letter are not significantly different at the .05 level.

burning and 104 to 109 ft^3 for supplemental treatments. Merchantable volume growth (trees over 3.5 inches d.b.h.) averaged 135 ft^3/acre annually for the unburned treatment, compared with averages of 103 to 110 ft^3 for the three burning treatments and 111 to 118 ft^3 for the three supplemental treatments. Pine basal area averaged 66 ft^2/acre for unburned treatments, and ranged from 54 to 60 ft^2 for the burning treatments, and 58 to 61 ft^2 for supplemental treatments.

Growth was least under the summer burn-check treatment combination, an averge of 65 ft^3/acre annually (Table 1). Much of this low growth can be attributed to pine mortality. For the entire study mortality averaged 1.6 trees/plot over the 7 years, or 16 trees per acre. However, losses for the summer burn-check treatment averaged 8.7 trees/plot, about 17 percent of the initial stand. Despite the reduction in stand density, survivors apparently did not respond with increased diameter growth. Average annual d.b.h. growth for this combination was 0.176 inches, less than any other treatment combination. Excluding the summer burn-check treatment, overall mortality averaged 1 tree per plot over 7 years, although higher on burned (1.2 trees/plot) than unburned (0.4 trees/plot) treatments. Trees that died averaged about the same size as survivors. If mortality on the three summer burn-check plots had been only one tree/plot, then annual volume growth (assuming added trees grew at the average rate) for this treatment combination would have increased from 65 to 86 ft^3, and the average for all summer burn treatments to 103 ft^3, similar to the other two burning treatments.

Cultural treatments had a highly significant effect on understory hardwood competition (Table 2). The chemical and handclearing treatments essentially eliminated larger hardwoods.

Table 2.--Understory treatment and number of hardwoods larger than 1.5 inches d.b.h.

Supplemental Treatment	Season of Biennial Burn				Average
	Winter	Spring	Sumner	None	
	(Stems per acre)				
Chemical	0	0	10	0	2a
Hand Clearing	0	0	0	0	0a
None	233	170	97	307	202b
Average	78ab[1/]	57ab	36a	102b	68

1/Column or row means followed by the same letter are not significantly different at the .05 level.

Among burning treatments only, numbers of hardwoods (over 1.5 inches d.b.h.) ranged from 97/acre with biennial summer burns up to 307/acre on the unburned check. Hardwood basal area for this latter treatment combination averaged 9.7 ft^2/acre. All of the small hardwood trees(0.5- to 1.5-inch diameter) were confined to the unburned-check treatment and numbered 1007 stems/acre. All burning and supplemental treatments had eliminated this component of the understory. Hardwood tree stems less than 0.5-inch diameter 6-inches above ground were numerous everywhere, averaging over 11 thousand stems/acre. Woody shrubs contributed an additional average of 159 thousand stems/acre. Cultural treatments affected small stem numbers but not nearly to the extent that it influenced trees above 0.5-inch in diameter. Dry weight of small woody stems (0.5-inch), both trees and shrubs combined, was highest on unburned-handcleared and unburned-check treatment combinations.

DISCUSSION

Results of this study indicate that the biennial burning regimes lessened longleaf pine growth. All measures of pine growth were significantly reduced by burning treatments, although excessive mortality on the summer burn-check treatment was partly to blame. It is not known why burning should have reduced the growth of this comparatively fire-resistant species, or why just one of the three summer burn treatments should have resulted in almost half of all recorded pine mortality. Recorded fire intensities were relatively low, due in part to lack of a heavy fuel build-up during the two years between burns.

The supplemental treatments eliminated nearly all hardwood competition above the 0.5-inch diameter class on all plots. Yet these treatments, while eliminating mid- and understory hardwoods, did not significantly improve pine growth. Over the first 7 years of this study, presence of a hardwood component comprising 13 percent of total plot basal area for unburned-check plots has not slowed pine growth, while all biennial burning treatments have. Apparently, under the conditions studied, competition on untreated plots was not great enough to adversely affect growth of overstory pine. None of the treatment combinations can be justified on the basis of improved pine growth, although some may be desirable because of other benefits resulting from changes in the structure and composition of understory vegetation.

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PRESCRIBED BURNING AND NITROGEN FERTILIZATION OF SLASH PINE PLANTATIONS[1]

A.V. Mollitor, N.B. Comerford, and R. F. Fisher[2]

Abstract.--To examine prescribed fire influences on urea fertilization of slash pine plantations, studies were established on flatwoods sites in Florida, Georgia, and South Carolina. Significant nitrogen fertilization responses were observed, and these responses were independent of burning regime. Apparently, nitrogen fertilization and prescribed burning are compatible silvicultural tools.

INTRODUCTION

For a variety of silvicultural and operational reasons, many slash pine (*Pinus elliottii* var. *elliottii* Engelm.) plantations are prescribed burned. Burning is often initiated soon after the trees reach sufficient size to be undamaged by fire. Forest fertilization is an increasingly common practice in slash pine plantations. Many stands are fertilized with phosphorus (P) at time of planting and again with nitrogen (N) at mid-rotation. Alternatively, N plus P may be applied at mid-rotation.

Because both prescribed fire and N fertilizers may be applied to stands at about the same time, there is some concern that fire may reduce fertilizer effectiveness. Although it is well known that fire may volatilize appreciable quantities of N (Wells 1971), long term effects on total soil N and forest productivity appear negligible (Stone 1971, Richter et al. 1982). However, burning the forest floor and understory vegetation in stands recently enriched by fertilization may be disproportionately wasteful of applied N.

In an effort to determine the compatability of prescribed burning and N fertilization, a series of three studies were initiated by the Cooperative Research in Forest Fertilization (CRIFF) program in 1976. This report summarizes third and fifth year measurement results.

METHODS

Tests were established in mid-rotation slash pine plantations in Nassau County, Florida (Test 1), Wayne County, Georgia (Test 3), and in Jasper County, South Carolina (Test 5). Tests 1 and 5 are on sandy, siliceous, thermic Ultic Haplaquod soils and Test 3 is on a sandy, siliceous, thermic Aeric Haplaquod. Initial stand conditions are indicated in Table 1.

Table 1.--Initial stand characteristics and changes in stocking rate for three burning-fertilization trials.

	Initial Stand Conditions					Stocking		
Test	Age yrs	Mean DBH in	Mean Ht ft	Basal Area sqft/ac	Total Volume cuft/ac	Yr0	Yr3	Yr5
						- -stem/ac- -		
1	14	4.7	34	69	1017	528	526	521
3	14	5.5	36	64	1049	372	370	361
5	15	4.6	38	76	1273	596	537	506

[1] Paper presented at Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Burning and fertilization treatments were applied in split-plot designs. Four burning treatments were applied in randomized complete block designs with three blocks (replications) determined by initial plot basal area. Burning treatments were (1) no burn, (2) burn four to five months before fertilization, (3) burn five to seven months after fertilization, and (4) burn four to five months before and two to three years after fertilization. Main plots were split into two subplots. One half was fertilized with 200 pounds N per acre as urea, the other half **recieved** no added N. All plots were fertilized with P. Specific treatment sequences are presented in Table 2.

Table 2.-- Measurement and treatment sequences.

	Test 1	Test 3	Test 5
	----	Date	----
Initial Measurement	Feb 76	Mar 76	Feb 76
Burn Before Fert.	Feb 76	Jan 76	Mar 76
Fertilization	Jun 76 1/	Jun 76 2/	Jul 76 3/
Burn After Fert.	Dec 76	Nov 76	Feb 77
Second Year Burn	Mar 78	Jan 78	Mar 79
Third Year Measurement	Nov 78	Dec 78	Apr 79
Fifth Year Measurement	Mar 81	May 81	Mar 81

1/ 200 lb. N/acre as urea, 80 lb. P/acre as CSP
2/ 200 lb. N/acre as urea, 100 lb. P/acre as CSP
3/ 200 lb. N/acre as urea, 50 lb. P/acre as CSP

Three and five growing seasons after fertilization, heights and breast-height diameters of trees on measurement plots were taken (Table 2). Total outside-bark volumes to a 3-inch top were determined using the equation of Bennet et al. (1959). Effects of burning and fertilization and their interaction on volume and diameter growth were evaluated by analysis of covariance using initial volumes and diameters, respectively, as covariates (Freund and Littell 1981). Single degree of freedom contrasts were used to compare (1) no burning with the average effect of burning treatments 2-4, (2) treatment 2 with treatment 3, and (3) the average effect of treatments 2 and 3 with treatment 4. Per-acre volume growth was estimated by multiplying adjusted mean tree volume growth by a single average number of trees per acre for each test (Table 1).

RESULTS

In no case was the burning-by-fertilization interaction significant (Table 3). This indicates that burning and fertilization responses were independent of one-another and can therefore be examined separately.

Burning responses were variable (Table 3). Test 1 showed decreased diameter growth on burned plots. Test 3 showed better five year volume and diameter growth on plots burned before fertilization than on plots burned after fertilization. Test 5 showed an early negative effect of fire, but by year 5 these differences were less obvious.

Response to N fertilization was significant in all cases. Fifth year volume growth was increased by 13 to 25 percent on fertilized plots, or about 30 to 54 cubic feet per acre per year. Diameter growth increased 17 to 38 percent (Table 4).

Figure 1 illustrates three- and five- year per-acre volume growth for individual burning and fertilization **conbinations.** Response to N is apparent across all burning treatments. For Tests 1 and 5, the general decrease in growth with burning can be seen. In Test 3, the superiority of volume growth for the before-fertilization burn is evident. Also, in contrast to Test 1 and 5, Test 3 shows an increase in growth in years 3-5 over that observed in years 0-3.

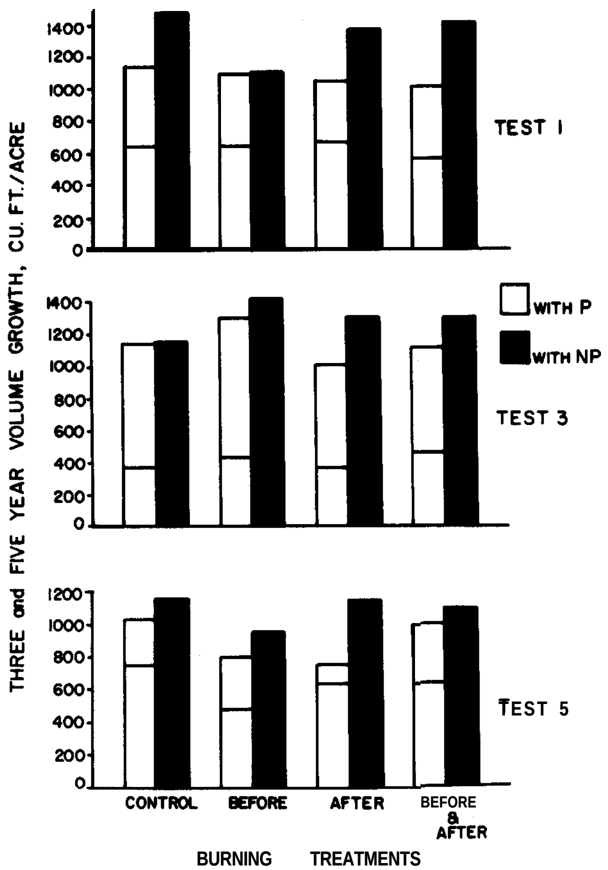

Figure 1. --Three-and five-year per-acre adjusted mean volume growth for individual burning-fertilization combinations. Horizontal lines within bars indicate third year means.

Table 3.-- Results of analyses of covariance of third and fifth year individual tree volume growth and diameter growth.

Source of Variation	d.f	Volume Growth						Diameter Growth					
		Test 1		Test 3		Test 5		Test 1		Test 3		Test 5	
		Yr3	Yr5	Yr3	Yr5	Yr3	Yr5	Yr3	Yr5	Yr3	Yr5	Yr3	Yr5
		- - - - - - - - - - - - -Probability of greater F- - - - - - - - - - - - - -											
Main Plots													
Replication	2	.01	.03	.54	.95	.02	.02	.01	.01	.54	.66	.01	.01
Burning	3	.65	.58	.06	.04	.17	.58	.33	.29	.24	.08	.86	.27
Split Plots													
Fertilization	1	.01	.01	.07	.09	.04	.06	.01	.01	.01	.01	.01	.01
Burn x Fert.	3	.53	.44	.65	.64	.91	.64	.63	.55	.51	.17	.86	.84
Contrasts													
Control vs. Burned	1	.41	.27	.02	.14	.08	.33	.20	.08	.78	.31	.06	.12
Before vs. After	1	.42	.48	.10	.02	.15	.66	.19	.49	.40	.02	.22	.40
Once vs. Twice	1	.71	.64	.48	.35	.89	.39	.86	.83	.08	.70	.65	.36

Table 4.--Three and five year individual tree adjusted mean total volume growth and diameter growth for burning and fertilization treatments.

	Volume Growth						Diameter Growth					
	Test 1		Test 3		Test 5		Test 1		Test 3		Test 5	
	Yr 3	Yr 5	Yr 3	Yr 5	Yr 3	Yr 5	Yr 3	Yr 5	Yr 3	Yr 5	Yr 3	Yr 5
	- - - - cubic feet per tree- - - - -						- - - - - - -inches- - - - - - - - -					
Burning Treatments												
No Burn	1.42	2.51	1.10	3.18	1.51	2.17	.6	1.1	.5	1.2	.8	1.1
Before Fertilization	1.28	2.10	1.27	3.75	1.07	1.73	.5	.9	.5	1.4	.6	.9
After Fertilization	1.40	2.32	1.17	3.18	1.34	1.88	.6	.9	.5	1.2	.7	1.0
Before and After	1.30	2.32	1.26	3.32	1.22	2.05	.5	.9	.6	1.3	.7	1.0
Fertilizer Treatments												
No Nitrogen	1.20	2.06	1.11	3.15	1.16	1.80	.5	.8	.5	1.2	.6	.9
200 lb. N/acre	1.50	2.57	1.30	3.57	1.41	2.15	.6	1.1	.6	1.4	.8	1.1

DISCUSSION

Burning effects were generally variable and small. For the two teats showing negative burning effects, is not known if the cause was an overall N loss or direct tree injury. Damage to the stand however, appeared minimal. The positive burning effects in Test 3 could be due to competing vegetation control or to response to nutrients released by burning. The increasing growth rates in years 3-5 suggest that this stand may have been P deficient . It is unfortunate that quantitative information on fire intensity and competing vegetation are not available for these studies. Some of the observed growth response variation could be due to burn-to-burn variation in intensity and efficiency.

Nitrogen responses observed in these tests are typical of slash pine plantations on flatwoods soils (Fisher and Garbett 1980). It is of practical importance to note that, as evidenced by the lack of a burning-by-fertilization interaction, prescribed burning within six months of urea application has no appreciable effect on this response. Thus, early summer fertilization and winter burning, either before or after fertilization, appear compatible.

It remains to be seen if burning more closely to time of fertilization might significantly affect N response. In these studies, the six month period between N application and post-fertilization burning was undoubtedly long enough to avoid significant volatilization of applied N. The quantity of applied N returned to the forest floor in needlefall and volatilized by second-year burns was most likely small.

CONCLUSION

Carefully planned prescribed burning of slash pine plantations should not interfere with nitrogen fertilization. Significant growth responses to N applications are common on flatwoods soils, and in addition to increasing overall growth rates, these responses may compensate for any small growth losses associated with burning.

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MAY BURNS BENEFIT SURVIVAL AND GROWTH OF LONGLEAF PINE SEEDLINGS[1]

HAROLD E. GRELEN[2]

Abstract.--Three replications of annual and biennial March and May burns plus an unburned control were compared 7 years in a direct-seeded stand of longleaf pine (*Pinus palustris* Mill.) seedlings in central Louisiana. May burning resulted in best survival and growth.

A fire is usually fatal to young seedlings of most pine species. But burning is beneficial--if not essential--to the survival and growth of longleaf pine seedlings. Brown-spot needle blight fungus (*Scirrhia acicota* (Dearn.) Siggers) infection and competition from other woody plants and herbaceous vegetation are factors that retard initiation of longleaf seedling height growth (Pessin 1944). Burning alleviates both problems, and earlier observations indicated that the effectiveness of fire is related to the season of burning (Grelen 1975).

Most prescribed burning in southern pine forests takes place during the dormant season, usually January through March. However, Bruce (1951) noted that light summer fires improved the early height growth of longleaf seedlings. In the early 1960's, the results of a season-of-burn study in Louisiana indicated that burning on or near May 1 was beneficial to the initiation of height growth by grass-stage longleaf seedlings (Grelen 1975). Croker (1975) found that longleaf seedling mortality following a May fire in Alabama was no greater than that after a fire in January. Two years later, Maple (1977) reported significantly greater growth by Croker's May-burned seedlings.

Because the Louisiana study in the 1960's was not designed to measure pine response, a new study was initiated in 1973 to compare the effects of March and May fires on longleaf pine survival and growth. This paper discusses final results of that study.

[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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METHODS

The earlier seasonal burning study was on a dry sandy site, so the new study was conducted on a moist, clay-loam soil. Thus, if similar results were obtained, conclusions might have a wider range of application. An area was selected on the Palustris Experimental Forest about 30 miles south of Alexandria, Louisiana, in an open pine-hardwood stand that had been direct-seeded to longleaf pine in 1968. The area had not been burned since 1970 and grass-stage longleaf seedlings were abundant in 1973. All large pines and hardwoods on study plots were removed or girdled to prevent overstory influences on treatment comparisons.

Southern bayberry (*Myrica cerifera* L.) was the dominant shrub, and young blackgum (*Nyssa sylvatica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), and blackjack oak (*Quercus marilandica* Muenchh.) were the common hardwoods. An abundance of accumulated herbage, predominantly bluestem grasses (*Schizachyrium* spp. and *Andropogon* spp.), provided fuel for first-year burning treatments. The area was not grazed for the duration of the study.

Burning Treatments

The following treatments were applied completely at random to three replications of contiguous quarter-acre plots:

March 1 annual burn
March 1 biennial burn
May 1 annual burn
May 1 biennial burn
Unburned control

Plots were burned within four days of the March 1 and May 1 target dates beginning in 1973, when most grass-stage seedlings were 5 years old. Annual fires were applied seven consecutive years, 1973-79, and biennial fires in the four odd-numbered years. Plots were burned with headfires when weather and fuel conditions permitted.

Pine Measurements

Before burning treatments began, 25 **grass**-stage **longleaf** pine seedlings and five seedlings already in height growth were permanently tagged on each treatment plot. Selected grass-stage seedlings had not yet formed a terminal bud, and the five seedlings already in height growth were less than 1 foot tall.

Survival and heights were recorded for all tagged seedlings after each growing season. Severe infections (more than 50 percent of foliage diseased) by the brown-spot disease were recorded for seedlings below 1 foot in height. Differences among treatments in survival, seedling height, and severe brown-spot infection were assessed by analyses of variance at the 5-percent level of probability .

RESULTS

Grass-stage Seedlings

No tagged grass-stage seedlings had begun height growth by the end of the 1973 growing season following initial burning treatments. Survival averaged 96 percent, with no significant differences among treatments. Through the third (1975) season, seedlings on plots of both May-burn treatments maintained highest survival percentages and the greatest percentage of survivors in height growth. Final survival on plots of the **May**-annual-burn treatment averaged 71 percent, significantly higher than other treatments, and all seedlings had begun height growth (Figure 1). Unburned plots averaged 45 percent survival, with slightly more than half the survivors in height growth by the end of the study.

Height growth of seedlings on plots of the two Play-burn treatments exceeded that of other treatments after the second year and for the remainder of the study (Figure 2). The two May-burn treatments, with final pine heights averaging 5.1 ft, did not differ significantly, but cumulative seedling growth on May-burn plots significantly exceeded that of the March-burn plots. Seedlings on the unburned-control plots averaged only 8 in tall at the end of the study, significantly less than all other treatments except the March biennial burn (Table 1). Tallest at the final measurement were two trees 12.5 ft tall on a May-annual plot, although average height for the May-annual treatment was only 4.8 ft.

Height-growth seedlings

The May-annual burn had the highest final survival at 93 percent, followed by the **March**-annual burn with 80 percent. Survival on these two annual-burning treatments did not differ significantly. Significantly lower seedling survival occurred with the biennial-burn treatments, which averaged 50 percent, and the **unburned**-control, which averaged 33 percent.

Throughout the study period, the May-annual burn led all treatments in tree height. The final average tree height on plots of this treatment was 16.1 ft, not significantly greater than that of the March and May biennial-burn treatments, but greater than the March-annual burn and the unburned control (Table 1). The tallest individual tree, also on a May-annual burn, was 22 feet.

Brown-spot needle blight

At the end of the first year, more than half of the measured seedlings on unburned control plots were severely infected by brown-spot. On these plots, shading and competition from rapidly growing woody plants combined with the disease to reduce pine survival and growth.

Severe infections on unburned control-plots increased during the second year to an average of 86 percent. Infected seedlings on March-biennial and May-biennial burn plots, unburned the second year of the study, increased from an average of 4 percent after the initial burn to more than 40 percent. Infection on annual-burn plots averaged 23 percent at the end of the second year.

By the end of the third year, in which all burning treatments were reapplied, infection in May-burn plots averaged 24 percent, significantly less that the 58 percent average on March-burn plots. Infection of seedlings on unburned-control plots averaged 76 percent, significantly greater than that of seedlings on any burning treatment.

After the third growing season, brown-spot measurements were discontinued because more than half of the seedlings on all but the unburned plots were in height growth. By the end of the study, 80 percent of the surviving seedlings on unburned-control plots were severely infected.

Reinfection by brown-spot following burning is rapid on small plots such as used in this study.2 Thus, higher infections might be expected in this study than on larger **brown-spot**-control burns.

SUMMARY AND CONCLUSIONS

Results from this and the earlier seasonal-burn study indicate that prescribed burning as frequently as feasible on or near **May 1** will improve survival and early height growth of **longleaf** pine seedlings.

3/ Derr, Harold **J.** Manuscript review **comment**.

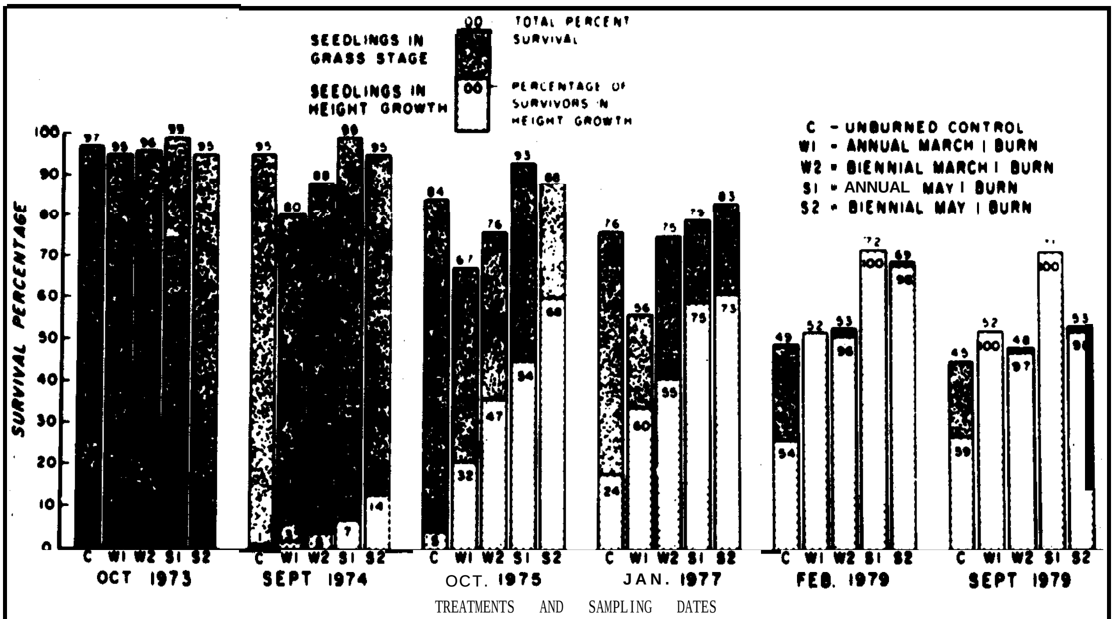

Figure 1.--Progressive survival percentages, showing percent of surviving seedlings in height growth.

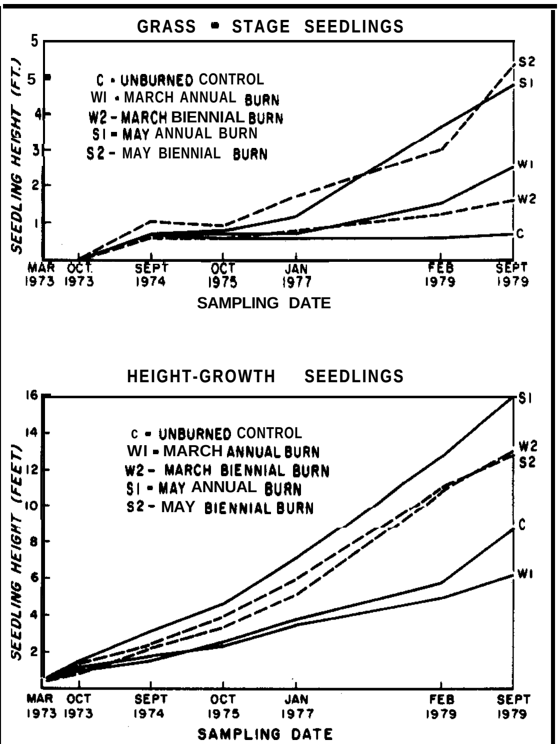

Figure 2.--Cumulative height growth of longleaf pine seedlings

Table 1. Final average survival and heights of sample seedlings in relation to burning treatments.

Burning Treatment	Grass-stage Survival (Percent)	Grass-stage Height (Feet)	Height-growth Survival (Percent)	Height-growth Height[1] (Feet)
March-annual	52 b[1]	2.5 b	80ab	6.2 b
March-biennial	48 b	1.6 bc	53 bc	13.0a
May-annual	71a	4.8a	93a	16.1a
May-biennial	53 b	5.3a	47 c	12.8a
Unburned	45 b	0.67 c	33 c	8.8 b

[1] Figures in columns followed by the same letter are not significantly different.

Frequent burns, especially annual fires, prevent the buildup of herbaceous fuel and the intense heat from a well-fueled grass fire. The new grass growth produced before a May burn also contributes to a cooler fire. New longleaf seedling growth, which in March is usually a silvery "candle", by May 1 is surrounded by an insulating sheath of elongating needles. Thus, the growing point is more protected in hay. But if competition and brown-spot are the two main factors hindering early height growth, the frequent burning of herbaceous competition and diseased foliage must be the key. Woody-plant root reserves are low around May 1, which may be a critical time for the release of longleaf from competition and brown-spot.

A reduction of woody cover and an increase of herbage was obvious on all burned plots. During the 7-year study, unburned control plots had grown into thickets of blackberry (*Rubus* spp.), loblolly pine saplings (*Pinus taeda* L.), and small hardwoods.

Growth might have been as great or greater if fires had been applied less frequently, especially after height growth had begun. After the fourth May-annual fire, survival on plots of that treatment dropped sharply. A number of trees that had begun height growth died or were killed back to ground level and had to start growth again from lateral sprouts. Longleaf 6 in to 4 ft tall are highly vulnerable to damage by fire (Bruce 1951), and more than half of the surviving seedlings on May-burn plots had begun height growth after three annual or two biennial May fires (Figure 1).

The burning frequencies used in this study may be too severe for operational burning programs. Where livestock grazing is an additional use of the plantation, fuel accumulation might not be adequate for effective annual or biennial fires. Thus, grazing should be excluded from longleaf pine regeneration areas if frequent fires are applied. While results of this study do not provide a recommended burning schedule for young longleaf pines, they suggest that frequent May fires can improve early survival and height growth.

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PRESCRIBED FIRE FOR HARDWOOD CONTROL AND FUEL REDUCTION

IN PINE PLANTATIONS ON THE CIJMBERLAND PLATEAU[1/]

Michael York and Edward Buckner[2/]

Abstract .--Fuel moisture and relative humidity were key factors controlling burn intensity. Topography strongly influenced wind movement: upslope fires generally burned as head fires while downslope fires burned as backfires. Both were equally effective for hardwood control and rough reduction. Disadvantages were that clownslope fires were slow-moving and upslope fires difficult to control.

INTRODUCTION

The Cumberland Plateau, an extension of the Appalachian Highland Region, extends across East Tennessee in a north-south direction, occupying approximately 5000 square miles. It varies in width from about 70 miles at the Kentucky-Tennessee border to 50 miles in northern Alabama. The eastern edge of the Plateau is a steep escarpment that rises approximately 1000 feet above the Ridge and Valley Province. The western margin, which is highly dissected by streams flowing from the Plateau surface, stands approximately 700 feet above the Eastern Highland Rim. Most of the Plateau is a gently rolling upland with an average elevation of approximately 2000 feet. The Plateau exists because a massive, horizontally beaded sandstone cap protects softer underlying shales, siltstones and clays from erosion (Phelps 1977).

Due to its height and exposure the Plateau has a cooler and wetter climate than adjacent regions to the east and west. Mean annual precipitation is 54 inches, but the shallow, sandy soils have a low water-holding capacity; soil nutrients are readily lost to leaching (Hasty 1948). The Plateau is approximately 70 percent forested. Native stands are characteristically low-quality upland hardwoods due largely to a history of repeated highgrading and frequent wildfires.

Much of the Plateau would be more productive if these native stands were replaced with pines (Murphy 1972). This potential and the availability of large tracts of land at relatively low prices has resulted in a large forest industry ownership. Over the past two decades, much of this region has been converted to loblolly pine (*Pinus taeda* L.) plantations. Even though it is not native to this area, loblolly pine grows faster than the native pines, even when planted considerably north of its natural range (Williston and Huckenpahler 1958; Walker 1962).

Despite the use of both chemical and mechanical measures for hardwood control, pine stocking and growth in most plantations suffers from aggressive hardwood competition. Heavy rough accumulations in older, well-stocked pine plantations and exposure to high winds make wildfire a continual threat. A safe and economical means for controlling hardwoods and reducing dangerous fuel levels is needed if pine plantation management is to be feasible on the Cumberland Plateau. Experience in the Coastal Plain suggests that prescribed fire might fill this need if safe techniques can be developed for using it in this rolling, hilly terrain.

Numerous studies have demonstrated the desirability of using prescribed fire for hardwood control on the flat terrain of the Coastal Plain (Riebold 1955; Neel 1965; McClay 1955; Klawitter 1959). These studies show that while single burns may kill a significant portion of the above-ground hardwood biomass, repeated bums are necessary to provide the rootstock kill that is essential to effective hardwood control (Grano 1970; Lotti 1962).

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Prescribed fires are also widely used to reduce heavy fuel accumulations thereby minimizing the danger of devastating wildfires. Cooper (1975) used backfires during the cool winter season to reduce heavy roughs that had accumulated over many years. Headfires, which reduce aerial fuels more than backfires, may be more attractive for successive fuel-reduction burns since they are less costly than backfires (Sackett 1975).

In recent years a few studies have demonstrated that prescribed fire can be used safely on sloping terrain in the South, Brender and Cooper (1968) found that both downslope backfires and upslope strip headfires were effective for killing hardwoods in a loblolly pine stand on the Georgia Piedmont. In the hilly Coastal Plain of Alabama, Chen, Hodgkins, and Watson (1975) found that burns during the growing season top killed more understory hardwoods than dormant season burns, and that sweetgum (Liquidambar styraciflua L.) and winged elm (Ulmus alata L.) were more susceptible to top kill than the oaks (Quercus spp.) and hickories (Carya spp.)

In a test of upslope and downslope headfires and backfires on sloping terrain in West Tennessee, de Bruyn[3/] found that downslope burns killed more hardwoods and consumed more fuel than upslope bums when burning conditions were marginal. When fires burned intensely, however, these differences were less noticable. Since the danger of wildfire was much greater under these conditions, downslope fires were recommended. He found that wind movement on sloping terrain tended to make downslope fires behave as backfires (i.e., wind direction is generally upslope during the day). This further reduced the rate-of-spread of downslope fires, accentuating their primary disadvantage, i.e., very slow rate-of-spread, enabling the treatment of only small areas during the limited periods when burning conditions were satisfactory.

The objective of this study was to develop safe and effective burning techniques for hardwood control and fuel reduction in pine plantations on the rolling terrain of the Cumberland Plateau.

3/ de Bruyn, Peter. 1981. Prescribed fire in a 23-year-old loblolly pine (Pinus taeda L.) plantation on sloping terrain in West Tennessee. Unpublished M.S. Thesis. University of Tennessee, Knoxville, Tennessee. 43 p.

METHODS

Study plots were located in a 26-year old, industry-owned loblolly pine plantation on an east-west oriented ridge on the Cumberland Plateau. The plantation was established following the clearcutting of a low-quality hardwood stand followed by chemical treatment to control residual hardwoods and hardwood sprouts. Several years after plantation establishment herbicides were applied by helicopter to selectively control hardwoods that were competing with the planted pines. Pine stocking was good on the south-facing slope but scattered hardwoods remained in the overstory on the north slope. Understory hardwoods were abundant on both slopes.

For each of 3 seasons (fall, spring, and summer) in which bums were tested, 4 plots were established, 2 on the north- and 2 on the south-facing slopes. These 12 plots provided for tests of both headfires and backfires both up and down slope. They were arranged in anticipation that a regional wind pattern would control where fires burned as headfires or backfires (i.e., where a fire was ignited at the base of one slope to burn as an upslope headfire, the headfire on the opposite slope would be ignited at the top of the ridge to burn downslope). Burn treatment plots occupied approximately 2 acres each, giving a total acreage burned for each season of approximately 8 acres.

In each burn plot 4 randomly located transects 9.8 feet wide and extending 164 feet in the up/downslope direction were established. All hardwood stems over 6 inches high were located on transect maps and tallied according to 0.4 inch diameter classes, diameter being measured 6 inches above the average groundline.

Immediately prior to burning, a steel cylinder 10 inches in diameter and sharpened on one end, was used to obtain 9 randomly located litter samples (to the litter-mineral soil interface), each of which was immediately placed in a plastic bag to prevent moisture loss. These were returned to the laboratory where moist weight and oven dry weight (at 70°C) were determined (to the nearest 0.1 gram) to provide both fuel moisture and fuel loading estimates.

Seasonal burns were carried out as follows: the fall bum was on October 22, 1979; the Spring burn on May 12, 1980; and the summer bum on August 27, 1980. Weather and fuel conditions on these dates are given in Table 1.

Table 1.--Weather and fuel conditions at the time of the 3 seasonal burns.

	FALL BURN	SPRTNG BURN	SUMMER BURN
Wind (m.p.h.)	2.40	1.64	0.50
Temperature (°F)	72	a4	a7
Relative Humidity (%)	71	54	45
Fuel Moisture (%)	40	22	31
Fuel Volume (lbs./ac.)	17,230	32,090	14,370

Suitable weather conditions for winter burns had been so infrequent in earlier phases of this project that they were not included in this study. These will be added to future studies as experience indicates they can occasionally be effective. The downslope backfire was always ignited first as its rate of spread was the slowest, while the **upslope headfire** was ignited last as it spread most rapidly. The average time required for fires to burn the length of the four 164 foot transects was used to calculate the rate-of-spread. Following each burn, litter samples were taken again to determine fuel reduction.

RESULTS AND DISCUSSION

The spring bums were by far the most intense of the seasonal tests, and most nearly achieved the goals established for this study, i.e., reducing fuels and controlling hardwoods (Table 2). Eowever, they also killed more of the pine crop trees.

Table 2.--Hardwood top kill, fuel reduction and crop tree mortality according to season of bum.

SEASON OF BURN	HARDWOOD TOPKILL	FUEL REDUCTION	LOBLOLLY PINE CROP TREE MORTALITY
	- - - - - - - -	PERCENT	- - - - - - - -
FALL	88	34	11
SPRING	98	66	22
SUMMER	90	33	7

The low fuel moisture on this date resulted in much greater fuel reduction than for bums in other seasons. While these fires were successful in killing back more of the large hardwoods, they were not otherwise better for hardwood control. Most of the crop tree mortality resulted from the **upslope, headfire** on the steeper southern slope. This fire spread at the rate of 577 feet per hour, the fastest of the 12 bums. Most of the dead pines were in the smaller diameter classes suggesting that such fires may function as a thinning from below under these conditions.

The summer burns on the northern slope where pine stocking was low due to aggressive hardwood competition in the overstory, were especially poor as the litter layer was largely decomposed and the surface organic matter that remained was compacted. On north and east aspects in this region the greater hardwood component in most pine plantations will likely create fuel conditions that make fires less intense and hardwood control more difficult. Brender and Cooper (1968) found that hardwood leaves form compact layers that restrict air movement, keeping lower leaves moist for longer periods of time.

Experience with these summer burns reinforces the observation made in other tests in Tennessee that summer burns will be difficult to carry out. High humidity is characteristic of this season, resulting in generally high fuel moisture levels. Although conditions appeared good for burning, these bums were sluggish and had to be continually reignited on the north slope where there was a large component of hardwood litter.

Relative humidity, fuel moisture, and wind speed were higher during the fall bum than during the other seasonal burns. Under these unfavorable conditions of relative humidity and fuel moisture, it is unlikely that the bum could have been conducted had it not been for the higher wind speed. This was the only time that winds were high enough to permit a downslope headfire.

Fires burned with greater intensity on the south slope as the litter was largely from the loblolly pine crop trees. In Alabama's hilly Coastal Plain Hodgkinsand Whipple (1963) reported that backfires in pine litter were more intense and consumed more fuel than backfires in hardwood litter.

As was true for an earlier phase of this project conducted in West Tennessee, wind movement was more strongly influenced by topography than by regional wind patterns. When regional winds were essentially absent, or when wind speeds were low, there was a strong tendency for **upslope** fires to burn as headfires and downslope fires as backfires. This was generally the case for the spring and summer burns, although behavior was often erratic.

This behavior is consistent with general observations regarding surface wind movement on irregular terrain. During the day when the ground surface is warming there is a tendency for warmed air to move **upslope** and form convection pillars along ridges. During the night this direction is reversed, with colder air building along the ground surface and this cool air "flowing" downslope (cold-air drainage). Because of the **upslope** movement of surface winds during the day the average rate-of-spread of **upslope** fires on both aspects was much greater than for fires burning downslope (Table 3).

Table 3.--Spread rates for **upslope** and downslope fires and their effect on hardwood **topkill,** fuel reduction and crop tree mortality.

FIRE TYPE	FIRE SPREAD RATE	HARDWOOD **TOPKILL**	FUEL REDUCTION	LOBLOLLY PINE CROP TREE **MORTALITY**
	Feet/hour	---- PERCENT	-----	
UPSLOPE	212	92	51	17
DOWNSLOPE	66	92	51	9

The burn having the most rapid rate-of-spread was consistently the one intended as an **upslope, headfire** and the slowest always the downslope, backfire. This indicates that while regional winds may not determine surface wind direction on sloping terrain, they do influence surface wind speed. Wind movement was generally greater on the south slope **as** it was steeper and the **slope-**length was much greater than that of the north aspect.

Downslope fires were as effective as **upslope** fires in reducing fuel levels and controlling all but the largest hardwoods (Table 3). Their very slow rate-of-spread was, however, a serious drawback. Unless long fire lines along ridges can be ignited, which is generally not possible in the dissected terrain characteristic of the Cumberland Plateau, these slow-moving fires will be too expensive for practical use in pine plantation management.

In the flat Coastal Plain, regional wind patterns uniformly affect the movement of surface fires. This is not the case on sloping terrain. A dangerously high regional wind would be required to uniformly drive a surface fire beneath a pine overstory on irregularly sloping terrain. **This** suggests that prescribed burning on irregularly sloping terrain should be done when **upslope** fires will be headfires and downslope fires backfires. The tendency on sloping terrain for daytime winds to be **upslope** (most pronounced on clear days) provides a degree of predictability to fire behavior. It further provides sufficient wind movement, when regional winds are too light to drive fires, to prevent the vertical flame pattern that is most likely to cause crown scorch and mortality in crop trees.

Since both **upslope** headfires and downslope backfires were equally effective in reducing fuels and hardwood competition (Table **3),** the problem becomes one of obtaining a rate-of-spread great enough to enable reasonable coverage during that part of the day having satisfactory burning conditions, yet not so intense as to kill crop trees. A topography-related igniting sequence that will be effective and safe for burning terrain such as that of the Cumberland Plateau has yet to be developed. The chevron-type burns, ignited along ridges and on hills, may provide a good starting point, but to enable sufficient coverage they will likely need to be supplemented with contour strip firing to speed burning of the slopes.

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INFLUENCE OF BURNING AND GRAZING ON SOIL NUTRIENT PROPERTIES AND TREE GROWTH ON A GEORGIA COASTAL PLAIN SITE AFTER 40 YEAR&

William H. McKee, Jr., and Clifford E. Lewis[2/]

Abstract .--Soil analysis of a study area in the Coastal Plain of Georgia indicates that 40 years of grazing and prescribed burning have had no adverse effect on concentrations of total nitrogen, available phosphorus, exchangeable bases, or organic matter in mineral soil. Burning alone reduced organic matter and nutrients in the forest floor and tended to increase them in the surface 6 inches of mineral soil. Grazing did not affect soil nutrient properties nor did grazing interact significantly with prescribed burning. Results indicate that well-managed grazing in conjunction with prescribed burning has no adverse effects on site quality for longleaf-slash pine-wiregrass sites.

INTRODUCTION

Burning to improve grass production and woods grazing is common throughout much of the Southern Coastal Plain (Lewis et al. 1982). Most studies on these practices have addressed forage quality, timber reproduction, burning frequency, and direct interaction of grazing and timber production. A subtle problem frequently overlooked is the effect that grazing and prescribed burning, which must accompany the grazing, has on future site quality and nutrient cycling in the forest floor and soil.

In this paper we report effects of grazing combined with biennial prescribed burning over a period of 40 years on nutrient levels on sandy Coastal Plain sites.

MATERIALS AND METHODS

Pastures were intensively sampled in 1980 after 40 years of prescribed burning and grazing research on a Coastal Plain site in Berrien County, Georgia. A portion of the Alapaha Experimental Range, which consists of a variable stand of longleaf and slash pine, was fenced into eight 50-acre pastures in 1942 so that two replications of four different prescribed burning regimes could be established. Burning treatments maintained until 1950 consisted of an unburned "control", triennial burning, biennial burning, and annual burning (Table 1). During 1950-54, the six pastures were burned annually. Beginning in 1954, fire was excluded from all pastures to permit reestablishment of pine by natural regeneration. The old mature trees were removed in 1961. An inventory of the trees in 1963 indicated that fairly similar stocking existed on all pastures. During 1965-67, biennial burning of pastures which has a previous burning treatment was initiated that continued to the present. The two unburned pastures have been protected from fire since 1941, when wildfire swept through the area.

The present timber stand consists of slash and longleaf pine with basal areas averaging 75 square feet per acre from 368 trees per acre (fig. 1). Average tree heights and diameters are 48 feet and. 5.7 inches, respectively, with no significant effects on tree growth due to burning or grazing.21 Understory vegetation consits of wiregrass range as described in detail by Halls et al. (1956).

All pastures were grazed at 8.3 acres per animal for 7 to 10 months per year from 1942-49. During 1950-54, grazing varied from light stocking at 17 acres per animal to heavy stocking at 4 acres per animal for 10 months of the year. Pastures

[1/]Paper presented at the Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 5-6, 1982.

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/Unpublished data: C. E. Lewis, USDA Forest Service, Gainesville, Florida.

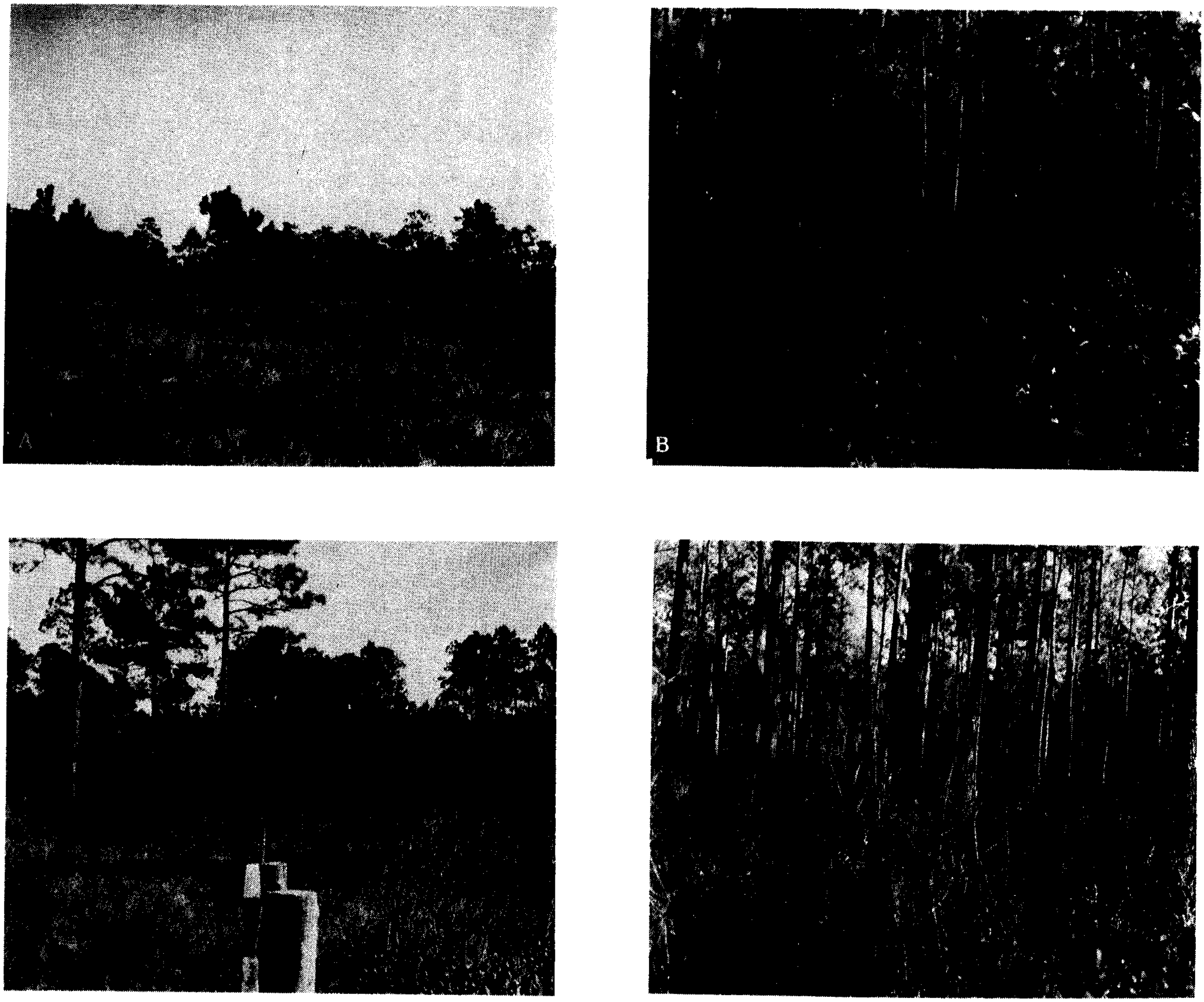

Figure 1. --Changes in tree6 and understory vegetation are evident on areas burned in 1941 as they appeared in 1942 on an Unburned treatment initially (a) and again in 1980 (b); and on a burned treatment initially (c) and again in 1980 (d).

Table 1.--History of burning treatments for pastures on Alapaha Range.

	Initial burning treatments and subsequent changes in fire management			
Years	Control	Triennial	Biennial	Annual
1941[1/]	Wildfire	Wildfire	Wildfire	Wildfire
1942-1949	Unburned	Triennial burns	Biennial burns	Annual burns
1950-1954	Unburned	Annual burns	Annual burns	Annual burns
1955-1964	Unburned	Unburned	Unburned	Unburned
1965-1982	Unburned	Biennial burns	Biennial burns	Biennial burns

[1/] The area was protected from fire from 1934 but a widlfire in 1941 burned about half of the experimental area.

were neither grazed nor burned from 1954-59 to allow for natural regeneration of pine. From 1960-66, pastures were stocked at 20 acres per animal along with 0.6 acres of improved pasture per animal for 10 months per year. From 1967-82, pastures have been grazed at this same intensity, but for only 6 months each year.

Soils in the study area are: Alapaha loamy sand (Arenic Paleaquult loamy siliceous thermic), a poorly drained soil making up about 2/3 of the study area; Leefield loamy sand (Arenic Plinthoquic Paleudult loamy siliceous thermic), a somewhat poorly drained soil representing about 1/4 of the study area; Irvington loamy sand (Plinthic Fraguidult fine-loamy siliceous thermic), a moderately well drained soil found on a relatively small portion of the study area; and Pelham loamy sand (Arenic Paleaquult loamy siliceous thermic), a poorly drained soil representing about 1/4 of the eight pastures but only 2 sampling areas in different pastures in the study (USDA, SCS 1975-80).

On upland portions (low ridges 2 to 5 feet above drainageways) within each of the eight pastures, six randomly located 1/4-acre fenced exclosures were established to exclude grazing. Adjacent to each exclosure is a like area with established corners but no fence. Samples were collected on two subplots in these 1/4-acre sample plots. At each subplot, forest floor and mineral soil samples were collected at four random points.

The forest floor was a mor humus that mixed little with the mineral soil. The forest floor samples included all material from the L, F, and H layers (litter, fungal, and humus) from within a 6-inch-square frame. No attempt was made to segment the forest floor by layers. Two 1-inch diameter soil cores were then collected from within the 6-inch squares. The cores were segmented into depths of 0-3 and 3-6 inches. The 0-3 inch sample represents the Al horizon and the 3-6 inch sample, in most cases, the A2 horizon, 6 inches being the lowest depth on which a measurable effect of burning was expected.

Forest floor samples were oven dried at 70°C for 24 hours, weighed, and ground to pass a 40-mesh screen. Nitrogen was determined by a modified micro-Kjeldahl procedure; 0.1 g of material was digested in a test tube, and ammonia content was determined by the salicylate-cyanurate procedure (Nelson and Sommers 1973). Other analyses were made on material dry-ashed for 2 hours at 450°C and taken up in 0.03 N HNO_3. Phosphorus was determined by the molybdovanadate procedure (Jackson 1958) and K, Ca, Mg, and Na by atomic absorption. A separate sample was dry-ashed at 500°C for 2 hours to determine mineral content, which was subtracted from the dry weight. Thus, weights of forest floor material represent only the loss on ignition component.

Soil samples were air-dried and crushed to pass a 2-mm sieve. Organic matter content was assayed by wet oxidation (Jackson 1958). Particle-size distribution was determined by .the hydrometer method (Day 1965). Exchangeable bases were determined by atomic absorption on extracts made with 1 N NH_4OAC (Jackson 1958). Available phosphorus was determined by extracting 2.5 g of soil with 20 ml of Bray P2 solution (Bray and Kurtz 1945). Soil pH was measured with a glass electrode on a 1:2 soil/water mixture. Total soil nitrogen was determined by micro-Kjeldahl digestion of a 1.0 g sample with ammonia being determined by the salicylate-cyanurate method (Nelson and Sommers 1973).

Results are expressed as concentration of nutrients in the soil components and as total amounts in the surface soil and forest floor. Bulk density values are taken from results published in an earlier report (Suman and Halls 1955). Comparisons of burning and grazing treatments are made by analysis of variance and "t" test with significance reported at the 0.05 level.

RESULTS

Soil

Nutrient concentrations were altered by the burning and grazing treatments (Table 2). Clay content of soils for the burning and grazing treatments ranged from 3 to 6 percent in the 0-3 inch soil layer and from 4 to 7 percent in the 3-6 inch soil layer. These soil textures are typical of many wet flatwoods.

Soil pH ranged from 3.50 to 4.39 for burning and grazing treatments in the 0-3 inch depth and from 3.77 to 4.52 in the 3-6 inch depth (Table 2). High acidity is typical of Ultisols throughout the Coastal Plain. Suman and Carter (1954) reported pH values of 4.7 in the 0-3 inch layer of soil and 4.8 to 4.9 in the 3-10 inch soil layer for this study area. Differences between their analysis and the present sampling may in part reflect different sampling techniques and seasonal variations in the soils.

Total nitrogen ranged from 282 to 435 parts per million in the 0-3 inch soil layer and from 144 to 213 parts per million in the 3-7 inch layer. These concentrations in the top 6 inches of soil are low in comparison to other sites in the Coastal Plain (McKee 1982); they reflect the sandy nature of the study site and its low nutrient holding capacity. Of interest is the slightly, but not significantly, higher level of nitrogen on grazed compared to ungrazed plots.

Concentrations of available phosphorus ranged from 2.4 to 3.3 parts per million in the 0-3 inch soil layer and from 1.7 to 2.3 in the 3-6 inch layer. These values fall in the range of those observed on a sandy site in Alabama (McKee 1982). As in other prescribed burning studies, concentrations of available phosphorus were higher on burned plots than on unburned control. Grazing had no noticeable effect on phosphorus levels.

Table 2.--Average chemical and physical properties for mineral soil as related to initial grazing and prescribed burning treatments during 1942-49. All burned pastures have been burned biennally since 1965-66.

Original burning treatment	Grazing treatment	Soil pH	Total nitrogen	Available phosphorus	Exchangeable bases: Calcium	Potassium	Magnesium	Sodium	Total bases	Clay	Organic matter
			- - - ppm - - -		- - - - - - - - meq/100 g - - - - - - - -					- percent -	
				0-3 Inch Soil Depth							
Control	None	4.07	282	2.4	0.12	0.01	0.05	0.09	0.27	5	1.78
	Grazed	4.05	304	2.5	0.11	0.02	0.04	0.07	0.24	6	1.82
Triennial	None	3.52	305	3.0	0.18	0.02	0.05	0.08	0.33	3	1.66
burning	Grazed	3.50	309	3.3	0.18	0.02	0.06	0.07	0.33	4	1.75
Biennial	None	4.39	378	3.2	0.33	0.02	0.08	0.08	0.51	5	2.17
burning	Grazed	4.31	435	3.3	0.26	0.03	0.07	0.06	0.42	5	2.21
Annual	None	4.14	406	2.6	0.16	0.02	0.05	0.09	0.32	4	1.59
burning	Grazed	4.13	412	2.8	0.15	0.02	0.05	0.08	0.30	4	1.72
				3-6 Inch Soil Depth							
Control	None	4.38	203	2.1	0.09	0.01	0.02	0.06	0.18	6	1.38
	Grazed	4.41	209	2.1	0.09	0.01	0.02	0.06	0.18	6	1.31
Triennial	None	3.77	144	2.1	0.11	0.01	0.02	0.06	0.20	4	1.25
burning	Grazed	3.82	165	2.3	0.12	0.01	0.03	0.06	0.22	4	1.40
Biennial	None	4.52	213	2.2	0.14	0.01	0.03	0.06	0.24	7	1.68
burning	Grazed	4.52	198	2.1	0.11	0.01	0.02	0.05	0.19	6	1.64
Annual	None	4.20	189	1.7	0.12	0.01	0.02	0.07	0.22	4	1.14
burning	Grazed	4.22	193	1.9	0.12	0.01	0.02	0.07	0.22	4	1.16

Concentrations of total exchangeable bases in the upper soil layer ranged from 0.24 to 0.27 milliequivalent per 100 g for the unburned control and from 0.42 to 0.51 milliequivalent per 100 g for the areas receiving biennial prescribed burns. All burning treatments contained slightly more exchangeable bases. Grazing had no noticeable effect on bases. In the 3-6 inch soil layer base concentrations ranged from 0.18 to 0.24 milliequivalent, and effects of treatments were even less apparent. The trend for burning to increase concentrations of most exchangeable bases in the A horizons is consistent with determinations made on other sites where prescribed burning was studied (McKee 1982, Wells et al. 1979). Although burning may have increased Ca slightly in the A2 horizon, it appears unlikely that burning mobilized any element to the extent that it moved beyond the upper part of the soil profile where roots are concentrated.

Organic matter concentrations in mineral soil were not strongly or consistently influenced by the prescribed burning treatments. These soils are typically low in organic matter. Of interest is the 0.04 to 0.13 percentage points higher organic content on grazed compared to ungrazed areas at the 0-3 inch depth. This trend was not apparent at the lower depth.

Forest Floor

Prescribed burning significantly reduced amounts of organic materials and nutrients in the forest floor (Table 3). However, any effects of the initial burning treatments (1942-54) on the forest floor properties aid not persist in the 1981 samples. Amounts of organic matter and nutrients were somewhat higher on areas burned annually than on areas burned less frequently. Grazing effects were not consistent and do not appear to affect measured forest floor properties.

Burning reduced the weight of organic matter in the forest floor by 69 to 88 percent and reduced that of nitrogen by 76 to 90 percent. The reductions in nitrogen content of the forest floor are similar to those of other burning studies (McKee 1982).

Phosphorus in the forest floor ranged from 12.1 to 17.2 pounds per acre without burning and. from 2.0 to 4.0 pounds per acre with burning. Prescribed burning also decreased the amounts of cations (calcium, potassium, and magnesium) by 66 to 89 percent. These changes are similar to those found on other Coastal Plain sites following burning (McKee 1982, Wells 1971).

Total Nutrient Budget

The changes in the forest floor and mineral soil are seen together (fig. 2). Bulk density values published by Suman and Halls (1955) for the soils in this study area were used to estimate quantities of nutrients per acre in the surface 6 inches of soil. At the time of sampling, the top 3 inches of soil in the grazed areas which were burned had higher bulk densities (1.48) than areas unburned (1.40) or areas burned and ungrazed (1.40).

Since only the biennial burning treatment has been applied consistently since the study began, and since the soils on this treatment's plots are similar to those of control plots, comparisons involving only this treatment and the control were

Table 3.--Organic matter and nutrient contents in forest floor as related to initial grazing and prescribed burning treatments. All burn pastures have been burned biennially since 1965-66.

Treatments		Forest floor content					
Original *burning* treatment	Grazing treatment	Organic X1000	Nitrogen	Phosphorus	Calcium	Potassium	Magnesium
		- - - - - - - -	- - - - - - - -	- pounds per acre -	- - - - - - - -	- - - - - - - -	- - - - - - - -
Control	None	59.7[1/]	514	17.2	85	15.1	24.5
	Grazed	46.5 A	369 A	12.1 A	64 A	10.9 A	16.5 A
Triennial	None	11.2	75	3.0	20	2.3	3.5
burning	Grazed	11.0 B	70 B	2.8 B	17 B	2.1 B	2.9 B
Biennial	None	6.2	46	2.0	12	1.5	2.3
burning	Grazed	7.0 B	54 B	2.1 B	15 B	1.5 B	2.4 B
Annual	None	13.6	97	3.5	24	2.9	4.0
burning	Grazed	16.2 B	107 B	4.0 B	25 B	3.6 B	5.1 B

[1/] Burn treatments with the same letter in columns are not significantly different at the 0.05 level.

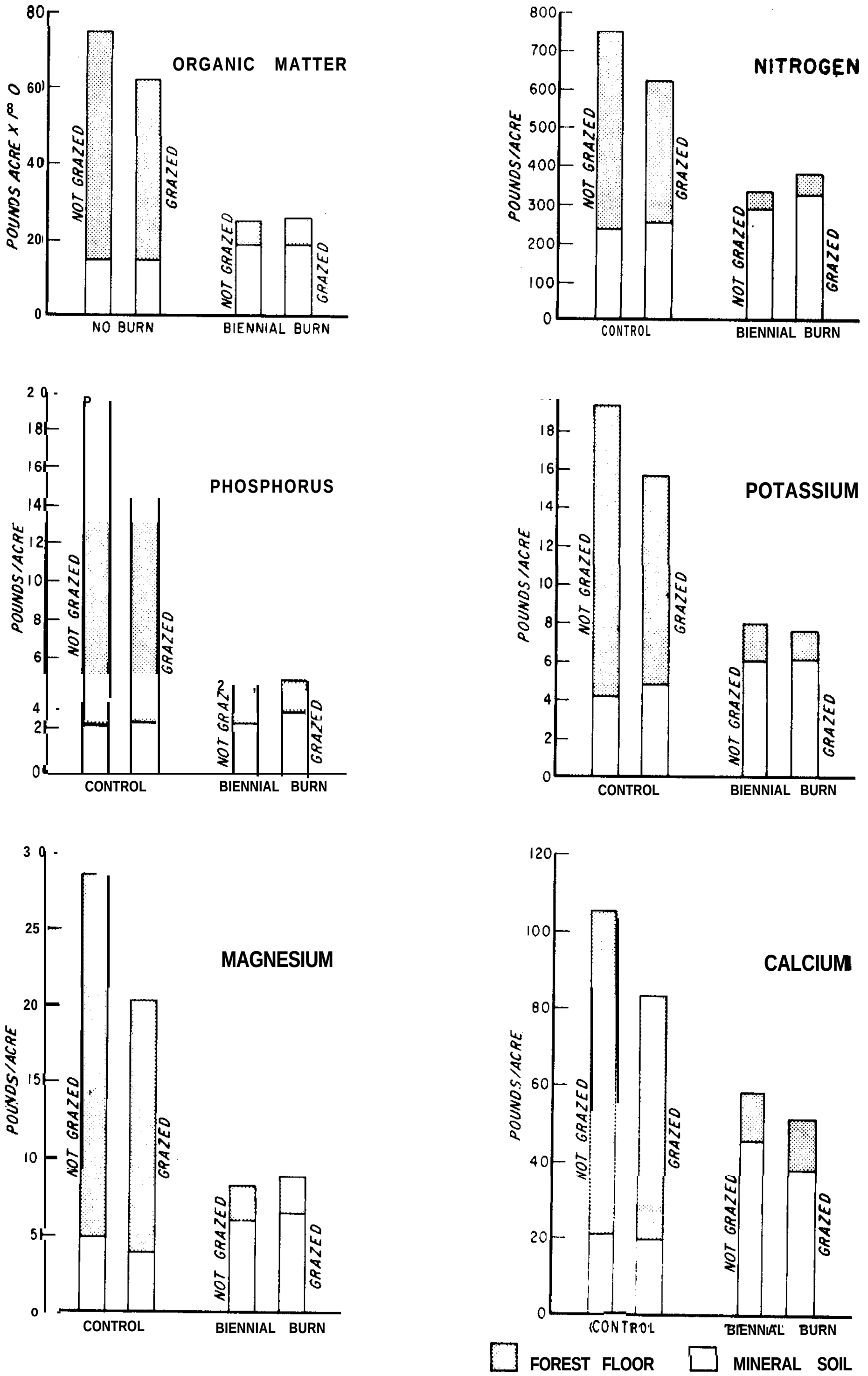

Figure 2.--Nutrient and organic matter content of forest floor and the surface 6 inches of mineral soil as they contribute to the total nutrient budget.

drawn. Amounts of organic matter and nutrients were compared by the "t" test of paired subplots at the 0.05 level.

While burning decreased the organic matter in the forest floor by approximately 40,000 pound5 per acre, it increased organic matter in the surface 6 inches of soil by 25 percent or 4,000 pound5 per acre. Grazing had no significant effect on organic content of the forest floor or soil with or without burning.

Nitrogen decreased in the forest floor and increased significantly in the mineral soil in much the same way as organic matter. The indicated increase of nitrogen in the mineral soil may result from mobilization of nitrogen by burning. In any case, the increase in readily available nitrogen stimulates plant growth. Grazing did not alter nitrogen content significantly.

A decrease in the ratio of forest floor organic matter to nitrogen found in other areas of the South with prescribed burning (McKee 1982) was not observed at this site. Here, ratios of organic matter to nitrogen appear to be unaffected by burning.

Burning decreased total phosphorus in the forest floor but significantly increased available phosphorus from 1.84 to 2.18 pounds per acre. A true comparison of phosphorus contents in the forest floor and soil is impossible because the forest floor analysis represent5 the total phosphorus present but the value5 for the soil are for available phosphorus. Grazing had no significant effect on phosphorus content in the total nutrient budget.

Although burning doubled calcium content in the mineral soil, it reduced the amount in the forest floor sufficiently to lower total calcium in the total nutrient budget. Grazing did not significantly alter total5 for calcium or other cations. Calcium contents for this site are 1/3 to 1/10 those of other sandy Coastal Plain sites where burning was studied (McKee 1982). A deficiency of calcium may develop without burning and affect either timber or forage production on such a site. However, no effect5 of burning on timber have been observed in the study.

Prescribed burning reduced the total potassium in the forest floor but increased exchangeable potassium in the soil. Grazing had no effect on potassium content. The increase in availability of potassium may be more important to forage production than to timber production since it is uncommon to find southern pine species responding to potassium fertilization (Pritchett 1979).

Magnesium contents of the forest floor and soil responded to treatments similarly to calcium and potassium. Burning reduced magnesium 7 to 10 fold in the forest floor but increased it by 1.6 pounds per acre in the A horizon. Higher amounts in the mineral soil may be important in maintaining a balanced nutrient pool for plant growth. Certainly, understory plants respond favorably to prescribed burning (Lewis et al. 1982).

CONCLUSIONS

Apparently any removal of nutrients over a long period by grazing or burning of understory plants on this site has not measurably reduced pine production. The intensity of grazing has been moderate, and it has not changed the nutrient status of the soil. If the cattle had any detrimental effects on the site quality, it would probably be through physical compaction of the soil (Suman and Halls 1955). It is possible on poorly drained sites that soil compaction will restrict organic breakdown and nutrient cycling; however, such an effect is not apparent on our study area.

Based on this long-term study, it appear5 that the combination of burning and grazing has no detrimental effects on the nutrient budget or on pine height or volume growth. Burning may in fact be beneficial to site quality through more rapid mineralization of nutrients. The responses of herbaceous vegetation and forage quality to prescribed burning have been described in other paper5 (Lewis et al. 1982).

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REGENERATION OF LOBLOLLY PINE PLANTATIONS IN THE PIEDMONT BY CLEARCUTTING WITH SEED IN PLACE[1/]

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Abstract.--Near-maturity plantations of loblolly pine in the Piedmont of South Carolina were successfully regenerated by clearcutting with seed in place. Three prescribed fires prepared the seedbed and adequately controlled hardwood competition. Two growing seasons after harvest, average seedling density on four watersheds was 21,160 stems/acre, but only about 3,400 were over 40 inches tall. An economic comparison of natural and artificial regeneration, plus the success of on-the-ground trials using natural regeneration demonstrates that clearcutting with seed in place is a viable low-cost alternative for regeneration of harvested pine plantations.

INTRODUCTION

Artificial regeneration of the Southern pines by clearcutting and planting has been a common practice for several decades. Initially, energy costs associated with mechanical site preparation were low, genetically improved seedlings were on the horizon, machinery was being developed that could overpower a site, and successful establishment of plantations was almost assured. Foresters became enthralled with the seemingly overwhelming advantages of artificial regeneration.

Artificial regeneration is expensive and most suited for landowners with capital to invest. Yet most forest land in the South is owned by small, nonindustrial landowners who can ill afford large initial investments. Neither do they have heavy equipment at their disposal for site preparation and planting, which, if improperly used, can physically harm the soil (May et al. 1973, Foil and Ralston 1967), especially in the Piedmont.

In recent years, the cost of artificially regenerating cutover stands has escalated to where only larger private industrial ownerships are willing to pay the required establishment costs. As a result, many harvested pine plantations are not being regenerated back to pine. For example, over 42 percent of all pine types harvested in South Carolina between 1968-78 have reverted to oak-pine or hardwood types (Sheffield 1979). In some other southern states, the percentage is higher.

In order to maintain the pine type on nonindustrial private lands, low-cost alternatives to artificial regeneration must be used. Natural regeneration is one alternative. Lotti (1961) discussed advantages and potential of natural regeneration for loblolly pine in the Coastal Plain by relying on seed from trees to be harvested. He called it clearcutting with seed in place. However, the technique has received little testing in the Piedmont.

The primary objective of our study was to evaluate the effect of prescribed burning and clearcutting on water quality of ephemeral Piedmont streams. This study afforded the opportunity to test clearcutting with seed in place under Piedmont conditions as a means of naturally regenerating loblolly pine plantations nearing maturity. In this paper, we discuss the techniques and results of the method, and the economic benefits that might ensue to the landowner.

METHODS

Study Area

Four small watersheds ranging from 1.5-3.1 acres and supporting 36 to 37-year-old loblolly pine plantations were studied. These stands are in the Clemson Experimental Forest in the upper Piedmont of South Carolina. Pine seedlings were planted in 1939-40 at 6 x 6 foot spacing. Pine basal area of three previously thinned watersheds ranged from 78 to 100 $feet^2/acre$, while the basal

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area of the single unthinned watershed was 143 feet²/acre (Table 1). There was little understory development in the unthinned stand, whereas the understory of the thinned stands contained black cherry (Prunus serotina ehrh.), blackgum (Nyssa sylvatica Marsh.), eastern redcedar (Juniperus virginiana L.), dogwood (Cornus florida L.), oak (Quercus spp.), and hickory (Carya spp.), Most understory stems were leas than 3 inches in diameter at ground line.

Soils on the watersheds are classified as typic Hapludults. Major soil series represented are Cecil, Madison, and Pacolet (Table 1). These soils are highly eroded after decade8 of row cropping, and the B horizon is now at or near the surface. Average slopes range between 11 and 16 percent and the mid and lower slopes are dissected by ephemeral stream channels.

Annual precipitation averages 51 inches and is generally well distributed throughout the year. In recent years, summer droughts of moderate-to-extended duration have occurred. Winter tends to be the wettest season with about 30 percent of the annual precipitation,

Prescription8 and Sampling Procedures

The four watersheds were burned three times to control the hardwood understory and prepare the eeedbed for natural seeding. The first burn (none of the stands had any history of previous burning) was applied to all four watersheds March 11, 1977, three days after passage of a cold front which delivered 0.8 inches of rain. Air temperature was between 50-59°F and relative humidity was about 40 percent. The second burn was accomplished on September 20, 1978. Burning conditions were good with relative humidity between 25 and 50 percent, wind speed between 5-10 mph, and air temperature between 81 and 90°F. About 2 weeks had passed since a significant rain, but high humidity had prevented excessive drying of fuels,

These two burn8 would have probably been adequate for controlling understory hardwoods and preparing the seedbed. However, since a major objective was to evaluate the effects of prescribed fire on water quality, a third burn was applied on September 12, 1979 to provide additional data to satisfy this objective. Relative humidity was between 55-60 percent, winds were about 10 mph, and air temperature was about 81°F. The last significant rain was about a week prior to burning and the three days before burning were cool and dry.

Burning technique was similar for all fires. A fire plow established a fuel break around each watershed. Back fires were set at the top of the slope against the fire break. After the back fire had moved downslope for perhaps 15 feet, strip head fires were ignited successively at about 30 feet intervals until the entire watersheds were burned,

Following the third burn, seedfall for regeneration occurred during the months of October to December. The watersheds were harvested between December 17, 1979 and January 10, 1980. Trees were felled with chainsaw8 and skidded in tree-lengths with a winch-equipped crawler tractor. Logging slash was left as it fell on watersheds 61, 66, and 68. On watershed 64, slash was bladed off the watershed to simulate whole-tree harvesting as part of another study.

Prior to the first burn, the forest floor was collected from ten 1-yard² plots on each watershed. Postburn samples were collected from adjacent plots about one month after burning. Samples were ashed so that weights could be expressed on an organic matter basis. Forest floor consumption during the second and third burns were estimated from measured litter weights, assuming 20 percent litter moisture content, using table VI-F-7 of the Southern Forestry Smoke Management Guidebook (U.S. Forest Service 1976). This data was collected on two of the four burned watersheds. Understory

Table 1. Site and stand characteristics of four watersheds.

Watershed No.	Size (ac.)	Slope (%)	Soil Series	Stand Age (yr.)	Stand Basal Area (ft.²/ac.)
61	1.6	13	Cecil, Madison	37[1]	143
64	2.8	16	Pacolet	36	97
66	3.1	11	Pacolet	36	78
68	1.5	12	Madison	36	100

[1]Age in 1975 when study began

vegetation and regrowth following harvest were sampled on four 1/40 acre plots on each watershed. The first Inventory of understory vegetation was just prior to the first burn. Subsequent inventories were at the end of the growing season following the first fire, and at the end of the growing season following the third burn, which was also one growing season following clearcutting. Seedfall was measured in ten 1-yard² traps/watershed between September and December, 1979. Seedling inventories were taken at the end of both the first and second growing seasons following clearcutting using 150 2.7 square foot quadrants/watershed.

RESDLTS AND DISCUSSION

One objective of the prescribed fires was to prepare the seedbed for natural regeneration. Burning with low intensity fires when the lower portion of the forest floor is moist, but the upper portion is crackling dry, consumes a relatively small proportion of the total forest floor (Richter et al. 1982). In this study, 7156 pounds/acre (about 1/3) of forest floor material was consumed in the first burn (Table 2). It was estimated that 3676 pounds/acre was consumed in the second burn, which was approximately equal to the litter fall following the first burn. About 1573 pounds/acre was consumed in the third burn, which was 1/2 of the litter fall following the second burn. About 7 1/2 tons/acre of forest floor material remained after the third burn. However, the loss of the strawbrown, loose and fluffy L layer gave the appearance that most of the forest floor had been consumed.

Table 2. Forest floor conaumption by three low intensity prescribed fires on watersheds 64 and 66.

Watershed No.	Litter Consumed First Burn	Second Burn	Third Burn
		-lbs./ac.-	
64	7093	4516	1918
66	7218	2839	1228

Transects across watersheds following burning indicated less than 1 percent mineral soil exposure following any burn. Retention of a large component of residual forest floor material is the principal reason why low intensity prescribed burning in these loblolly pine plantations had no adverse effect on erosion (Douglass and Van Lear, in press).

The second objective of the prescribed fires was to control hardwood competition, which may greatly reduce seedling survival and growth (Trousdell and Wenger 1963, Langdon 1981). The first burn dramatically reduced the number of hardwood stems between 0.5-2.5 inches (Table 3); but because of resprouting, the number of stems present in the < 0.5 inch diameter class the first growing season after burning increased sixfold. Stems were not counted after the second fire; but one growing season after the third fire, only 10 percent of the small diameter stems remained. Thus, these repetitive fires significantly reduced both total number and size of the hardwood competition.

The most serious competition for the naturally seeded pines would be expected to come from stems in the 0.5-1.5 inch diameter class. One growing season after harvest, there were 520 stems/acre in this diameter class with an average height of about 3.9 feet. However, this competition is not as severe as these numbers indicate, since many of these sprouts occurred in scattered clumps of multiple stems.

Table 3. Size-class distribution of hardwood competition before and after the first burn and after the third burn In near-maturity loblolly pine plantations.

Diameter Size Class	Pre-Bum Burn	Post-First Burn	Post-Third Burn
- in. -		- #/ac. -	
< .5	3,040	18,640	1,683
0.5 - 1.5	800	0	520
1.5 - 2.5	360	40	2
2.5 - 3.5	0	40*	0
Total	4,200	18,720	2,205

* Ingrowth from the 1.5-2.5 inch class

Timing of the seedbed preparation is critical when regenerating stands using clearcutting with seed In place. If burned too early, regrowth of competing vegetation will dominate the site before seedlings can become established. If burned too late, seed on the ground will be consumed by the fire. The last burn, therefore, should be late summer or early fall. Harvest can proceed after seed is in place but prior to spring germination.

Seedfall during the fall of 1979 ranged between 79,400 to 116,200 seed/acre for the four watersheds. Seedlings began germinating in early April and continued until mid-May as frequent rains favored germination. At the end of the first growing season, stocking averaged 17,195 seedlings/acre. Despite 53 percent mortality during a dry first growing season and subsequent droughty conditions, reseeding from the adjacent uncut stands increased stocking to 21,160 seedlings/acre by the end of the second growing season (Table 4).

Table 4. Average height, diameter, and density of loblolly pine seedlings two growing seasons after regeneration by clearcutting with seed in place.

Watershed NO.	height	Basal Diameter	Density
	- in. -	- in. -	- #/ac. -
61	19.8	.3	13,171
64	20.6	.3	30,337
66	20.7	.3	27,098
68	17.1	.2	14,035
Average	19.6	.3	21,160

Logging exposed mineral soil on 20-25 percent of watersheds 61, 66, and 68 where logging slash was left on site. However, blading off all logging slash on watershed 64 exposed nearly 50 percent bare soil. This probably accounts for the high stocking on this watershed.

A preliminary analysis of seedling height distribution indicates that precommercial thinning may not be needed despite high stocking levels. Seedling heights ranged from 8 to 70 inches after three growing seasons; about 16 percent of the seedlings, or about 3,400/acre, were greater than 40 inches. These taller seedlings should compete successfully with the other vegetation that invaded the site. Distribution of seedlings, as determined by the percentage of plots stocked with at least one seedling was excellent, averaging 78 percent for the four watersheds after the second growing season. The wide variety of microsites on these dissected and terraced watersheds may allow rapid differentiation into crown classes and negate the need for precommercial thinning. Further evaluation will be necessary.

Thus, under the conditions of this study, clearcutting with seed in place is a viable method of naturally regenerating loblolly pine in the Piedmont. But can the landowner afford it, and how do investments in natural regeneration compare with those made in artificial regeneration?

A cash-flow analysis comparing natural regeneration using seed in place with artificial regeneration by mechanical site preparation and planting was performed. A number of assumptions were made (Table 5). This analysis (Table 6) showed that a landowner could naturally regenerate five times the acreage as could be artificially regenerated for a given investment, assuming the indicated regeneration costs. His rate of return, after taxes, would be 16.4 percent for his investment in natural regeneration versus 12.2 percent for his investment in artificial regeneration.

In some cases, precommercial thinning may be necessary to reduce the stocking of overly dense natural stands. Assuming a cost of $35/acre for the precommercial thinning, the economic analysis indicated a rate of return on natural regeneration of 17.8 percent and nearly twice the acreage regenerated as compared to artificial regeneration. The higher rate of return for the precommercial thinning treatment is primarily due to the shortened rotation, i.e. 25 years versus 30 years for natural regeneration without precommercial thinning. Thus, precommercial thinning would be a good investment, although it would restrict the number of acres that could be regenerated if only a limited amount of capital is available for regeneration and early culture.

From an economic standpoint, natural regeneration by clearcutting with seed in place would be attractive to small timberland owners, both from the standpoint of return on the investment and the increased acreage that can be regenerated for a given sum of money. However, it must be emphasized that natural regeneration using this method does not just happen; it must be planned years in advance of harvest. Hardwoods must be controlled by one or more prescribed burns, or other methods, and seedbeds must be prepared at the proper time of year. Harvest must occur after seedfall but before germination and be designed to enhance seedling establishment. Natural regeneration is more dependent on rainfall distribution, especially during the germination period.

To make natural regeneration a viable low-cost alternative to artificial regeneration, the forester will have to become more familiar with stands nearing maturity to prescribe treatments for seedbed preparation and hardwood control and to assess potential seed crops. Natural regeneration methods do work, but foresters will have to use their knowledge of silvics and silviculture to a greater degree to achieve consistently satisfactory results.

Table 5. Assumptions in an economic comparison of artificial and natural regeneration with and without precommercial thinning.

Artificial Regeneration	Natural Regeneration	
	No Precommercial Thinning	Precommercial Thinning
Piedmont site - S.I. 70' supporting well-stocked loblolly pine with understory of small hardwoods	same site and stand	same site and stand
rotation - 25 yrs.	30 years because of slowed growth due to high initial stocking	25 years because precommercial thinning prevented slowing of early growth
volume produced will be 29 cords/ac. in 25 yrs.*	29 cords/ac. in 30 years	29 cords/ac. in 25 years
pulpwood, at today's prices, is $12/cd and will increase at 5% for the next 25 years to $40.64/cd	pulpwood price - $12/cd, increasing at 5% for the next 30 years to $51.86/cd	pulpwood price - $12/cd, increasing at 5% for the next 25 years to $40.64/cd
site preparation (root rake and windrow) + planting = $100/ac.	regeneration by clearcutting with seed in place using 2 burns at $10 each for seedbed preparation	regeneration by clearcutting with seed in place with precommercial thinning ($35/ac.) at age 5, plus two burns ($20/ac.) for seedbed preparation

The following assumptions apply to all three situations: $1000 is available for investment in regeneration and early culture; the landowner is in a 28% tax bracket; 6% alternative investment rate is applied to intermediate incomes; capital gains treatment of harvest revenues is claimed; and initial investments received a 10% investment tax credit and 7 year amortization.

* We make the unproven, but suspected, assumption that the growth increase from using genetically improved seedlings will be offset by site degradation from mechanical site preparation. Therefore, yields for artificial and natural regeneration will be similar.

Table 6. Summary of cash-flow analysis comparing rates of return on artificial regeneration with two cases of natural regeneration, based on the assumptions in Table 5.

Activity	Year	Artificial Regeneration	Natural Regeneration: Without Precommercial Thinning	Natural Regeneration: With Precommercial Thinning
First burn	- 1	NA	-$ 500.00	- $ 182.00*
Second burn	0	NA	500.00	182.00
Site preparation and planting	0	- $ 1,000.00	NA	NA
Investment, tax credits. (10%)	0-1	+ 100.00	+ 100.00	+ 36.40
Amortization of initial investment	O-8	+ 280.00	+ 280.00	+ 101.92
Precommercial thinning	5	NA	NA	636.00
Deduct thinning costs on personal tax return	6	NA	NA	+ 178.08
Interest earned on reinvested incomes**	0-25 26-30	+ 841.16 NA	+ 870.78 + 329.35	+ 1,152.80 NA
Tax on interest earned	1-26 27-31	- 235.53 NA	243.79 92.23	322.83 NA
Harvest income (acres regenerated x projected pulpwood price/cd)	25 30	+ 11.786.00 NA	NA + 75,197.00	+ 21,450.00 NA
Tax on harvest income	26 31	- 1,320.03 NA	NA - 8,422.06	- 2,402.40 NA
Effective compound annual rate of return	--	12.2%	16.4%	17.8%
Acres regenerated = $1000/regeneration + early cultural costs	--	10	50	18

* Only $364 ($182 x 2) would be available for the seedbed preparation burns because $636 would be needed for the precommercial thinning at age 5. Total investment = $1000.

** Reinvested incomes include investment tax credits, tax refunds from amortization of initial investment and deduction of thinning costs, and $636 held for five years until thinning occurred.

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REGENERATING LOBLOLLY PINE BY NATURAL SEEDING AND BY PLANTING IN SOUTHEASTERN LOUISIANA[1/]

S.C. Hu[2/]

Abstract -- A study was conducted to compare the success of clearcutting followed by planting with that of natural regeneration of loblolly pine (*Pinus taeda* L.) by seed-tree, shelterwood, and selection methods. --

Results after 4 years showed that the seed-tree method had the best milacre stocking with 56 percent. The free-to-grow seedlings in clearcut areas were the tallest and had the largest diameters, whereas in selection areas the free-to-grow seedlings were only 1.9 feet in height and less than 0.5 inches in diameter.

It has been estimated that the demand for timber in the U.S. will be greatly increased by the year 2000 and that the South is destined to supply an increasing proportion of the nation's timber needs (U.S. Forest Service 1973). However, the trend among nonindustrial landowners in the South today is toward deforestation. For most of the 15 million acres of nonindustrial forests harvested during the past ten years, no provisions were made for regeneration (Jordan & Balmer 1982). If the increasing demands for timber are to be met, sound management of our forests, including effective regeneration is very important in order to maximize timber production from a steadily decreasing forest acreage in the South.

Although loblolly pine (*Pinus taeda* L.) is one of the most important and most widely distributed timber species in the South, few studies have been conducted to compare the effectiveness of the various natural regeneration methods with hand planting. Small landowners lack information as to the most suitable regeneration method for their forest. The purpose of this study is to compare the success of clearcutting followed by planting with that of natural regeneration of loblolly pine by seed-tree, shelterwood, and selection methods.

The study areas are located on the Middle Coastal Plain at LSU's Idlewild Experiment Station near Clinton, LA and Lee Memorial Forest 10 miles west of Bogalusa. The predominant speices at the Idlewild study site was loblolly pine mixed with shortleaf pine (P. *echinata* mill,) and associated hardwoods. The- loblolly pine was a mature stand, ranging from 50 to 65 years old. Basal area of loblolly pine on the study site ranged from 49 ft^2/acre to 94 ft^2/acre. The major soil series are Providence silt loam, Lexington silt loam, and Ruston sandy loam. The site index for loblolly pine is 100 (Base age 50) at Idlewild. At Lee Forest, the loblolly pine, mixed with hardwoods, averaged 50 years old and its basal area ranged from 60 ft^2/acre to 99 ft^2/acre. Site index for loblolly pine on the study site at Lee Forest is 90; the major soil series is Ruston fine sandy loam. In each location, 160 acres of mature loblolly pine stand were divided into eight 20-acre plots (10 chains x 20 chains). Four regeneration methods, clearcut, seed-tree, shelterwood, and single-tree selection, were randomly assigned among plots; and two replications were established in each location.

During the summer of 1978, harvest cuttings were made on clearcut, seed-tree, shelterwood, and selection areas in both locations. Six trees per acre were selected and retained in seed-tree areas, and 20 trees per acre were chosen and left in shelterwood areas. All merchantable trees were harvested in clearcut areas, and only a small portion of loblolly pines was selected and removed from selection areas in 1978. After harvesting, the clearcut areas were chopped, burned, and hand-planted at a spacing of 8' x 8' in February 1979. The seed trees left in shelterwood and seed-tree areas were finally removed in

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1980 (two years after harvest). Year-end checks of regeneration were made each year in both locations. During the latest inventory in 1982, the total number of seedlings was counted; and the heights and diameters at ground level of the free-to-grow seedlings were measured. In order to eliminate side effects, only the interior 10 acres of each 20-acre plot were sampled by use of 20 milacre plots. The fourth-year results are presented in Table 1.

Results show that the shelterwood treatments have the highest number of seedlings, averaging 2,700 per acre. However, most of the seedlings in the shelterwood areas are small and overtopped by hardwoods. These overtopped seedlings may not survive without some form of release. A more accurate picture of the future stand should be based on at least one free-to-grow seedling per milacre. The seed-tree method has the best milacre stocking with 56 % free-to-grow seedlings. Derr and Mann (1971) reported that 55 % is a commonly accepted minimum criterion for successful milacre stocking. The other three treatments (clearcut, shelterwood, and selection) are not so well stocked. However, Campbell and Mann (1973) stated that 40 % stocking after three years is considered the lower threshold for an acceptable stand. On this basis the clearcut-with-planting (48 %) and shelterwood treatment (47 %) are stocked in acceptable numbers. The selection treatment has only 25 % of its milacres stocked with free-to-grow seedlings. Since this regeneration method is designed to produce an uneven aged stand, it is difficult to judge the success of this method at the present time.

The average heights and diameters of the free-to-grow seedlings for the seed-tree and shelterwood treatment are almost identical. However, the average heights and diameters of these two treatments differ greatly from clearcut and selection methods. The free-to-grow seedlings in clearcut areas are the tallest (11.8') and have the largest diameters (2.3"), whereas in selection areas the free-to-grow seedlings are only 1.9 feet in height and less than 0.5 inch in diameter at the ground level.

The selection method requires much knowledge and skill to apply efficiently and takes a continuing commitment to carry out the regeneration process. It may not be wise for a small landowners to use the selection method to regenerate loblolly pine stands, except for a special reason, such as wildlife or soil and water protections.

The seed-tree method has more free-to-grow seedlings and is generally less expensive than planting. Because fewer trees are required to be left in the seed-tree method than in shelterwood and selection methods, there is less logging damage to the seedlings when the leave trees are harvested. However, the seed-tree method should not be considered superior to other methods solely on the basis of this study. The choice of a regeneration method should be made after careful consideration of all biotic and economic factors which may affect the results and economics of the method.

Table 1. Fourth-year inventory of loblolly pine seedlings by regeneration method in Louisiana.

Rating factor & Unit	Clearcut with hand-planting	Seed-tree	Shelterwood	Selection
Total seedlings/AC. (no.)	1750	2250	2700	2212
Ave. Ht.of free-to-grow seedlings (ft.)	11.8	7.8	7.5	1.9
Ave. dia. of free-to-grow seedlings (in.)	2.3	1.4	1.3	<0.5
Milac. stocked w/seedlings (%)	65	74	68	54
Milac. stocked w/free-to-grow seedlings (%)	48	56	47	25
Milac. stocked only w/overtopped seedlings (%)	17	18	21	29

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CHOCTAWHATCHEE SAND PINE SURVIVAL, HEIGHT, AND BIOMASS IN SOUTH CAROLINA: THIRD-YEAR RESULTS[1/] [2/]

W. Henry McNab[3/]

and

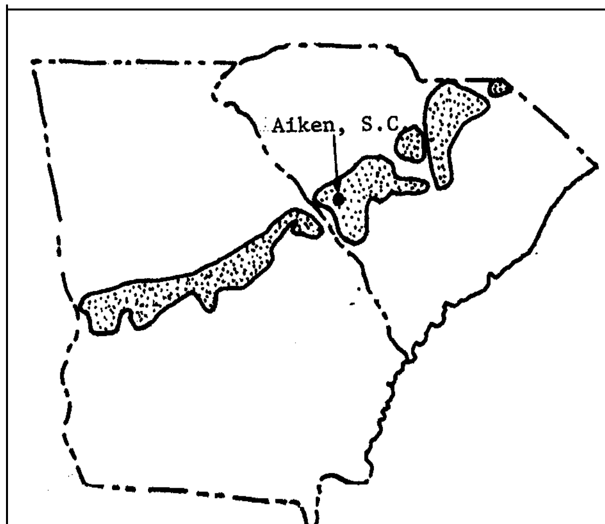
R. H. Brendemuehl[4/]

Abstract.--Choctawhatchee sand pine (*Pinus clausa* var. *immuginata* Ward) seedlings from three Florida nurseries were planted on deep sand, scrub oak sites in South Carolina to study effects of nursery seedling source, soil amendments, planting method, and grade on survival and growth. Three years after planting, survival averaged 68 percent and height 3.2 feet. Neither nursery of origin nor soil amendment treatment significantly affected survival or height. Machine-planted seedlings had significantly greater survival than those planted by dibble-bar. Seedling morphological grade had greater effect on height than on survival. Prediction equations are given for estimating total-tree and component green weight from tree height and diameter at the base of the crown.

INTRODUCTION

Over 6 million acres of commercial forest land in Georgia and South Carolina are in the Sandhills physiographic province (figure 1). Soils there are largely dry, infertile, deep sands. Longleaf pine (*P. palustris* Mill.) was the main commercial species on these sites, but it was cut and did not adequately regenerate, possibly because natural seed sources were insufficient. Many areas are now stocked with low value stands of scrub oaks (Burns and Hebb 1972). Regeneration with longleaf pine often is not attempted because seedling mortality is usually high and site productivity is low.

Although its natural range is largely restricted to Florida, Choctawhatchee sand pine is a promising alternative to longleaf pine for fiber and biomass production in the Georgia and South Carolina sandhills. In small scale tests in Georgia and South Carolina, Choctawhatchee sand pine performed better than loblolly (*P. taeda* L.), slash (*P. elliottii* var. *elliottii* Engelm.), Ocala sand (*P. clausa* var. *clausa* (Chapm.) Vasey), and longleaf pine (Hebb 1982). In some larger plantings in Georgia (Preston and Price 1979) and South Carolina (McNab and Carter 1981), sand pine has also performed well.



Source: Burns and Hebb 1972

Figure 1.--Principal areas of sandhill soils in Georgia and South Carolina.

Choctawhatchee sand pine is comparable with other southern pines for conventional products (Brendemuehl 1981). Interest also has developed' in utilizing Choctawhatchee sand pine as a biomass species because of its high fiber production at

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close spacing on dry sites (Rockwood et al. 1980), but biomass prediction equations are available only for planted trees 6 years of age and older.

This paper reports early survival and height growth, and biomass prediction equations for Choctawhatchee sand pine in research and commercial size plantings on the Savannah River Plant (SRP), near Aiken, South Carolina.

METHODS

Choctawhatchee sand pine seedlings were obtained from three nurseries in northwest Florida. Two of the nurseries, one operated by the Florida, Division of Forestry (FDF) and the other by industry (IND), supplied 1-0 seedlings. The third nursery, on the Chipola Experimental Forest (CEF), maintained by the Southeastern Forest Experiment Station, supplied 2-0 seedlings. Nursery management and lifting procedures were not recorded. Randomly selected samples of seedlings from each nursery were measured and weighed. Root/shoot ratio was calculated by dividing root fresh weight by shoot fresh weight.

Seedlings were stored at 40" F in their original packaging container until planting. FDF and IND seedlings were packed root-to-root, in open-ended bales. Sawdust was used to keep IND seedling roots moist. Roots of the FDF seedlings were dipped in a clay slurry at the nursery. The CEF seedlings were packed in sealed poly-kraft bags. Water was added periodically to keep the roots moist.

Seedlings were planted during February and March 1979 on various sites and by different methods, and survival and height growth were monitored. Two types of field plantings were established. Small, statistically designed studies were used to evaluate effects of nursery seedling source and soil amendments. Larger, nondesigned areas were planted to evaluate problems and results of operational handling and planting of Choctawhatchee sand pine. Significant treatment differences in the statistically designed experimental plantings were determined using Duncan's Multiple Range Test at the 95 percent level of probability. Results from larger plantings were evaluated by comparing average survival and height in randomly selected rows of seedlings.

Research Plantings

Effects of nursery source on survival and height growth were determined on Lakeland (Typic Quartzipssmment) soils prepared by windrowing and root raking. Seedlings were planted with dibble-bars at 10X10 foot spacing, on 0.06 acre plots, replicated three times in a complete block design.,

Anaerobically digested, dried sewage sludge (estimated to contain about 3% N and 1% P), from Aiken, SC, was evaluated as a soil amendment on a small area of Lakeland soil that was site prepared by disking the ground cover of grasses, lichens, and cacti. CEF seedlings were dibble-bar planted by a single operator at 5X5 foot spacing on 0.01 acre plots. A complete block design replicated three times was used to test six treatments: (A) sewage sludge broadcast and disked at a rate of 18.2 tons per acre or about 0.5-inch deep; (B) sewage sludge broadcast and disked at a rate of 9.1 tons per acre; (C) 1 cup of dried sewage sludge placed in the closing hole; (D) 1 cup of sawdust placed in the closing hole; (E) 10-10-10 "fertilizer broadcast at a rate of 5.4 tons per acre in a split application: one-half was applied before disking and the balance was applied in July; and (F) control, no treatment. Treatment D simulated the organic matter in treatment C, but without nutrients. The total amount of nitrogen applied in treatment E was about the same as that in treatment A.

Operational Plantings

Two larger areas were operationally planted to evaluate effects of methods of planting and morphological grade on survival and growth. Planting method was evaluated on 5 acres of Lucy (Arenic Paleudult) soil that had been prepared by shearing and windrowing. Lucy is a well-drained soil with sand only about 40 inches deep, and is usually planted in loblolly pine. A single operator planted seedlings from the three nurseries with a Whitfield wildland planter and a dibble-bar at a single spacing. The effect of topsoil displacement during site preparation on this area was evaluated by comparing height of seedlings planted in the first row parallelling windrows, with height of seedlings planted in the second row, about 8 feet away.

FDF seedlings were visually graded as large, medium, or small. They were machine-planted on a 2.5-acre tract of Lakeland soils which had been prepared by prescribed burning 3 years earlier, and twice unsuccessfully planted to longleaf pine.

Prediction equations for estimating the total-tree and major component green weight of individual stems were developed from a sample of 18 trees, ranging from 1.6 to 7.3 feet in height, that were growing on Lakeland soils.

RESULTS AND DISCUSSION

Precipitation on the SRP averages about 47 inches annually, and is usually well distributed throughout the growing season. During the first, second, and third years after planting, annual precipitation averaged 55, 43, and 48 inches. Seedling survival and height were determined on all planted areas during the early spring of 1982, after three growing seasons.

Initial Size Comparisons

Seedlings from the three nurseries differed in size, weight, and appearance (figure 2). Root systems of CEF seedlings were small, and the FDF seedlings were largest, except for average top length (table 1). Seedlings from all sources had at least 8 inches of top growth, which is desirable for outplantings (Sampson 1973). First-year top growth for the 2-0 CEF seedlings in the nursery bed was 6.5 inches.

Nursery Source Comparisons

Source nursery did not significantly affect total-height or mean plot survival, even though sizes of seedlings differed by nursery. Average

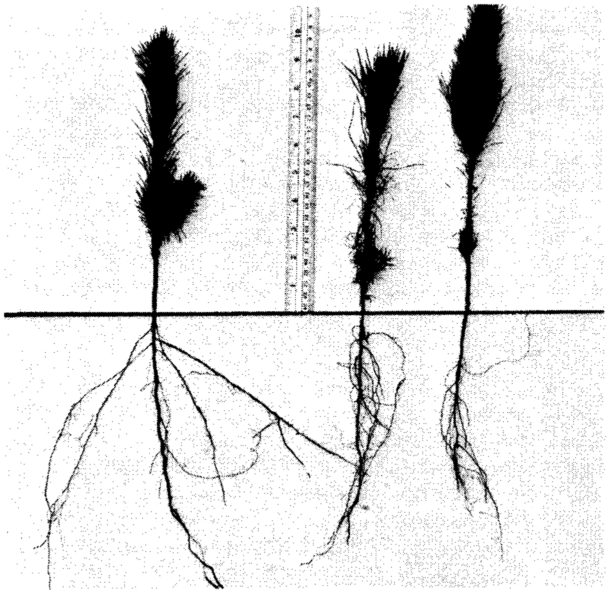

Figure 2.--Typical Choctawhatchee sand pine seedlings from the Florida Division of Forestry, Industrial, and Chipola Experimental Forest nurseries.

Table 1.--Size and weight of Choctawhatchee sand pine seedlings from three source nurseries

Nursery source	Top length	Root collar diameter	Shoot weight	Root weight	Root/ shoot ratio
	- - - Inch - - -		- - - - - Gram - - - -		
FDF	a.4	0.15	8.19	2.54	0.31
IND	a.7	.10	3.40	.82	.24
CEF	10.7	.12	7.19	.98	.14
Average	9.3	.12	6.26	1.44	.23

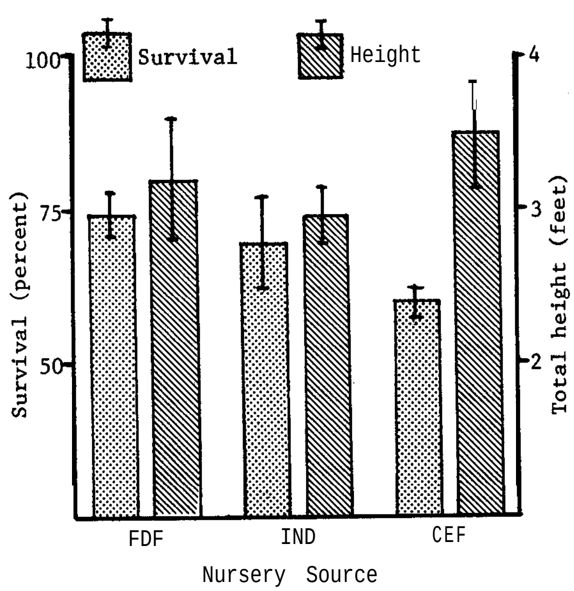

Figure 3.--Third-year survival and height of sand pine seedlings from three sources planted on Lakeland soils, ± standard error of the mean.

third-year survival and height of dibble-bar planted seedlings from the three nurseries are shown in figure 3. Considerable variation was present in the field data, as shown by the standard errors of the mean. The low survival rate for the 2-0 CEF seedlings indicates little practical advantage in leaving sand pine seedlings in the nursery bed an additional year, unless they are surplus to current needs and can be used the following year (McLemore 1982). Working with the Ocala variety of sand pine, Cooper et al. (1959) reported that lower survival of 2-0 seedlings was probably due to smaller root-to-shoot ratios. These results indicate that source nursery may not be as important to survival and growth of sand pine seedlings as it seems to be for longleaf pine (Parker and Haines 1980).

Soil Amendments

Average survival and height of seedlings planted after various soil treatments was:

Treatment	Survival	Height
	Percent	*Feet*
A	81.2	3.9
B	81.2	3.3
C	87.5	3.3
D	81.2	2.9
E	66.7	2.7
F	70.8	2.9

None of the treatments shown are significantly different from the control or each other.

Brendemuehl (1972) reported a height and diameter response to N and P fertilization by sand pine seedlings in a greenhouse and by 4-year-old saplings in the field. The lack of height response to 10-10-10 fertilization in this study may have been due to inability of the newly planted seedlings' restricted root system to effectively utilize the soluble nutrients before leaching occurred in the sandy soils. Although sewage sludge did not significantly benefit seedling height at 3 years, the slowly released organic forms of N and P in the sewage sludge will be available for seedling growth over a longer period.

Applying large amounts of readily available nutrients at the time of planting is not economical and may increase seedling mortality. Other vegetation, especially grasses and cacti, quickly responded to surface applications of sewage sludge and fertilizer, and competed with the sand pine seedlings for soil moisture. The very high concentration of soluble salts in the commercial fertilizer may have increased mortality by reverse osmosis of water from the roots of some newly planted seedlings. Most mortality occurred during the first three months after planting and little thereafter.

Planting Method

Machine and dibble-bar planting were compared using all seedling sources on an area prepared by shearing and windrowing during the previous summer. Seedlings planted with the dibble-bar averaged over 0.5 foot taller than those planted by machine, but this difference was not statistically significant (table 2). In general, CEF seedlings were tallest among the three sources and grew particularly well when planted by dibble-bar.

Table 2.--Effects of dibble-bar and machine planting methods on survival and height of sand pine seedlings from three nurseries

Nursery source	Survival		Height	
	Dibble-bar	Machine	Dibble-bar	Machine
	- - - *Percent* - - -		- - - *Feet* - - - -	
FDF	76	88	3.6	3.5
IND	56	95	4.0	3.5
CEF	76	83	5.1	4.0
Average[1/]	69*	89	4.2ns	3.7

[1/] * indicates difference in mean survival is significant at the 0.95 percent level; ns indicates the difference in mean height is not significant.

Mean survival was 20 percent higher for seedlings planted by machine compared to dibble-bar; this difference was significant at the 5 percent level in a t-test of unpaired plots. Part of this difference may be attributed to excessive drying of fine roots during hand planting. Overall, mean survival of dibble-bar planted seedlings was 69 percent, about the same as for the nursery source test, but the individual survival rates of IND and CEF sources were different. Cooper et al. (1959) found no significant difference in survival when planting Ocala sand pine with dibble-bar compared to machine.

Regardless of nursery source or planting method, survival of Choctawhatchee sand pine has remained almost constant since the first field check was made 3 months after establishment. In contrast, annual mortality in stands of other species on sandhill soils is relatively high (Brendemuehl 1981), which makes the final level of stocking uncertain.

Seedlings planted next to the windrows averaged 4.0 feet in height while seedlings in the next row averaged only 3.5 feet. The difference in height was significant based on a paired t-test and indicates that nutrients and organic material in the displaced topsoil can affect seedling growth on a moderately fertile site. On infertile sandhill soils, choice of site preparation methods that conserve available nutrients is even more important.

MORPHOLOGICAL GRADE

The FDF seedlings used in this test varied widely in size and appearance (figure 4). Root collar diameter averaged 0.21, 0.14, and 0.11 inch for samples of large, medium, and small seedlings. Grade had little effect on survival, which averaged about 95 percent overall:

Grade	Survival	Height
	Percent	*Feet*
Small	93.6	3.6
Medium	95.1	5.1
Large	95.7	5.0
Average	94.9	4.6

Grade, however, did influence height at age 3; small seedlings were about 1.5 feet shorter than medium or large seedlings. These results indicate that grade seems to be less important in planting Choctawhatchee sand pine compared to other species, especially longleaf pine (White 1978).

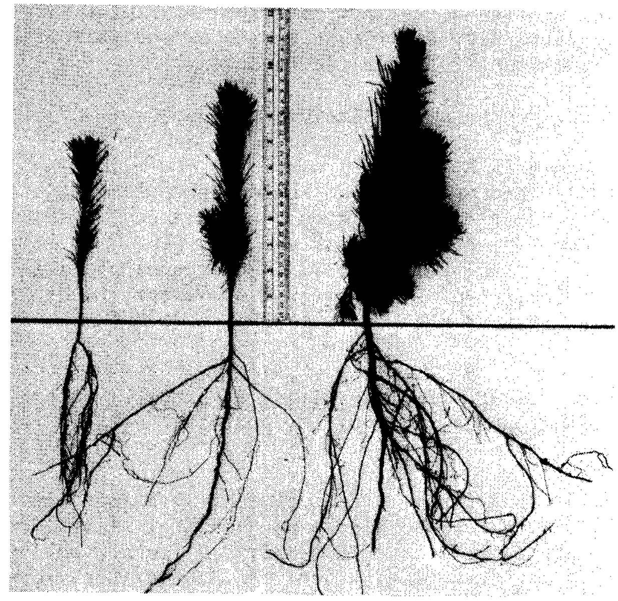

Figure 4.--Small, medium, and large grades of Choctawhatchee sand pine seedlings from Florida Division of Forestry nursery.

Survival of seedlings in this test was excellent, despite an unplanned, long period of refrigerated storage. FDF seedlings were held for 28 days at 40° F and planted in early March, when air temperature ranged from 65-75" F. Under proper conditions, Choctawhatchee sand pine seedlings can be stored for relatively long periods with little loss of vigor. Burns (1975) machine-planted Choctawhatchee sand pine seedlings stored in unrefrigerated bales for 1 to 8 days, and found no difference in first-year survival.

Biomass Prediction

Prediction equations developed for estimating green weight of total tree wood, bark, and foliage (TTWBF), wood and bark (TTWB), and wood (TTW) are:

$$\text{TTWBF (lbs)} = 0.83488 \times \text{DBC2TH}^{0.67030} \quad (1)$$

$$\text{TTWB (lbs)} = 0.42228 \times \text{DBC2TH}^{0.68162} \quad (2)$$

$$\text{TTW (lbs)} = 0.25344 \times \text{DBC2TH}^{0.79348} \quad (3)$$

where:

DBC2 = squared stem diameter at the base of the crown in inches,
TH = total height in feet.

The coefficients of determination (R^2)--0.96, 0.94, and 0.95 for equations 1, 2, and 3--indicate a close relationship between tree component green weights and the independent variable. Because the prediction equations were developed from saplings at only one location, the user should verify the accuracy of estimated weights.

Early survival and growth of Choctawhatchee sand pine seedlings from three nurseries planted in the South Carolina sandhills does not seem to be strongly affected by seedling grade, which may result from variation in nursery management practices, or by soil amendments. Choctawhatchee sand pine seedlings can be reliably planted by machine with high survival. Early survival is a good indication of stocking throughout the rotation.

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FACTORS INFLUENCING SURVIVAL AND EARLY STOCKING TRENDS IN PLANTATION OF LOBLOLLY PINE [1/]

G. Kenneth Xydias [2/]

Abstract.--About 500 plots were established on a variety of planting sites over a two-year period on land owned by Continental Forest Industries. Detailed observations were made for each tree and planting spot shortly after planting and again after one year. Counts of live planted trees were obtained two and three years after planting. Survival was only poorly related to initial conditions of the tree or planting spot. Ninety-five percent or more of the trees that survived the first growing season continued to survive in subsequent years.

INTRODUCTION

Foresters have been establishing pine plantations in the South for more than 30 years. There can be little question that much of this planting effort has been successful. However, many examples of poor survival have been noted. Williston (1972), in reviewing survival records over a sixteen-year period of planting on the Yaxoo-Little Tallahatchie Flood Prevention Project, found that only three of those years had survival percentages exceeding eighty percent. Likewise, Marler (1963), showed that survival experience for a three-year period in the Virginia coastal plan never exceeded eighty percent. More recently the American Pulpwood Association polled its members as to their plantation establishment practices and survival experience. The membership generally reported a relatively stable survival trend until the mid-1970's when declines were noted (Weaver and others 1982).

The reasons for poor survival are always uncertain. Drought conditions either at planting or during the first growing season afterwards is a favorite one (Wakeley, 1954, Malac, 1965). Others include nursery practices including lifting and packing (Weaver and others 1982, Barnard and Hollis 1980), storage under freezing conditions (McClurkin 1966); and improper planting of seedlings. Proper seedling care and handling from the nursery through delivery to an intermediate storage area is discussed by Brissette and others, (1981), while Xydias and others, (1981) follow this through the planting job.

The reasons for poor survival must be identified before they result in a failure so that corrective action may be taken. Too often, reasons are postulated to explain failures but whether that explanation is correct is another matter. Corrective actions based on erroneous assumptions may be worse than taking no action at all.

STUDY DESCRIPTION

This study is part of the survival studies established by Continental Forest Industries and reported previously (Xydias 1980). It is known as the post mortem study and was established for two reasons. One was to provide detailed information about why individual trees died, and how their death could be related either to attributes of the tree or of the planting spot. The other reason was to provide a data base which could be used to test hypothesis about site or management factors associated with survival.

The study consists of two series of plots established in successive years beginning in the 1978-79 planting season. Plots established in the 1978-79 season are referred to as the first

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series while those established the following year are referred to as the second series. Both series were established in newly planted areas throughout company ownership.

In each of the two series, plots were established in planting sites that were selected to cover a range of conditions with respect to methods of site preparation, time of planting, and soil conditions. One or more plots were located at each planting site in an area thought to be representative of a larger landscape unit. Information gathered for each plot include dates for completion of significant management activity such as cutting, site preparation, and planting, a characterization of the site, and for the second series a description of environmental conditions at the time of planting.

Plots were of such a size that about 60-80 planting spaces were observed. Each planting spot was numbered sequentially and the ground conditions within a six-inch radius were classified. Classes recognized included bare ground, fine debris, coarse debris, herbaceous competition, woody competition, root mat, eroded, or deformed bed. If the planting spot contained a tree, its condition was identified as being healthy, unhealthy, or dead. If the tree was unhealthy or dead, an attempt was made to assign a reason for these conditions. Other attributes of each tree were also noted. These included size (small, average, or large), position after planting (horizontal, slanted, or vertical), and planting depths (unplanted, shallow, normal, or deep).

Plots were visited again during the dormant season following the first year's growth and the ground conditions for each planting spot were characterized for a second time. If the planting spot contained a tree, its condition and the reason for its condition were noted. Almost 80 percent of the second series plots in the Hodge district were in areas of such poor stocking that replanting was necessary. Only counts of live planted trees were obtained for these plots.

Plots of both series that had not been replanted or otherwise abandoned were again visited following the second growing season. In this and subsequent visits, counts of both live planted trees and of free-to-grow volunteers were obtained, but detailed observations of each tree or planting spot were not obtained. An attempt was made to avoid unrealistically high counts for volunteers by constraining counts to only two volunteers if the planting spot did not have a tree and only one if the spot had a tree.

The first series of plots were also visited following the third growing season and counts of live planted trees and free-to-grow volunteers were again obtained. Third-year counts are currently being obtained for the second series of plots. Fifth-year counts are planned for both series.

The geographical range for plot establishment is shown in Figure 1. It extends throughout company ownership from Virginia south to north Florida, and also occurs as an island in northwestern Louisiana. This area is organized by Continental into four woodlands districts, with the district name indicating a town close to the location of a pulp mill. It also refers to a single decentralized administrative unit for accounting and management purposes. Analysis has generally been done by districts, although this breakdown may mask some meaningful sources of variation.

RESULTS AND DISCUSSION

First-Year Survival

Survival percentages associated with a variety of percentiles along with the number of plots visited are given in Table 1. Survival ranged from less than five percent up to one hundred percent. Both the median survival and the distribution of survival varied from district to district and from year to year. Generally, however, survival was much better for the first series of plots than for the second series. Survival in the first series was almost acceptable even for survivals as low as the tenth percentile in all districts except for Hopewell. In contrast to this, survival for this second series was marginal at the fiftieth percentile except for the Savannah district. The second series survival was especially poor in the Hodge district, with an extreme drought during the summer of 1980 resulting in the need for replanting almost 80 percent of the acreage planted during the previous year.

Factors Related to Survival

Survival is influenced by so many factors that identifying cause and effect relationships may be an impossible task. It varies form year-to-year and from planting job to planting job. For this discussion, only the conditions of the planting spot and the attributes of individual trees will be considered as possible factors.

A SAS[1/] program was written to summarize the classification data for each planting spot and tree, and convert these summaries to percentages. This resulted in the definition of 30 different variables that could be related to survival of an individual plot. The summary program also cal-

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l-1 SAS is an acronym for the Statistical Analysis System.

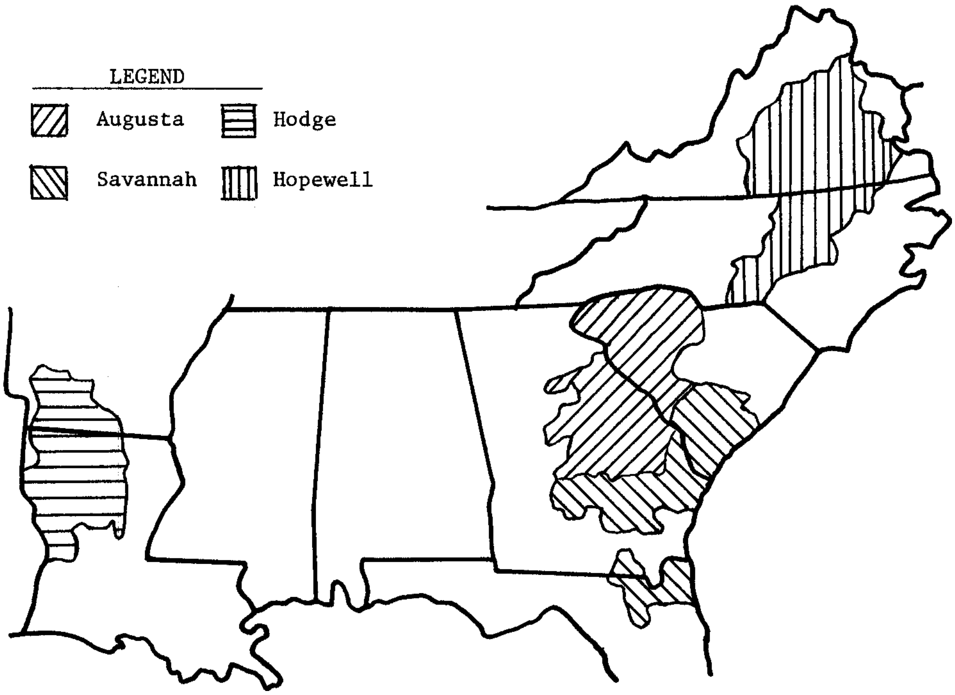

Figure 1. Geographical range for the post mortem plots.

culated survival, took the square root of it, and transformed it to its arcsin equivalent.

Variable names and their meanings are given in Table 2. Note that each variable name identified the attribute under consideration (planting spot, tree size, planting depth), the level of the attribute and the visit in which it was observed. For example, all variable names beginning with the word "spot" refer to the planting spot. Variable names ending with the number one refer to conditions observed at the first visit, while those ending with a two refer to conditions observed a year later at the second visit.

Graphs of survival against the various independent variables showed no evidence of curvilinearity so only the simple linear correlation coefficients between each of these variables and survival were calculated. Significant values are shown in Table 3 for the first series and in Table 4 for the second series. Since correlation

Table 1 .--Survival for a range of percentiles by series and district

Series	District	Plots	Percentile 5	10	50	90	95
			Percent				
First	Augusta	43	54	68	91	98	100
	Hodge	62	57	62	85	95	97
	Savannah	72	60	62	87	98	99
	Hopewell	81	40	47	75	93	96
Second	Augusta	59	32	39	67	93	96
	Hodge	58	5	10	50	82	84
	Savannah	50	30	40	79	91	91
	Hopewell	77	20	28	59	84	86

Table 2.--Variable names used in the correlation analysis.

Variable	Percent With	Variable	Percent With
SPOTB1	Bare ground	DEPTHS1	Shallow planted
SPOTF1	Fine litter	DEPTHN1	Normal planted
SPOTC1	Coarse litter	DEPTHD1	Deep planted
SPOTH1	Herbaceous weed	SPOTB2	Bare ground
SPOTR1	Root mat	SPOTF2	Fine litter
SPOTW1	Woody shrub	SPOTCZ	Coarse litter
SPOTD1	Deformed bed	SPOTH2	Herbaceous weeds
SPOTE1	Eroded	SPOTR2	Root mat
SIZES1	Small	SPOTE2	Eroded
SIZEN1	Normal	SPOTW2	Woody shrub
SIZEL1	Large	SHALLOW	DEPTHU1 + DEPTHS1
POSH1	Horizontal	LITE1	SPOTB1 + SPOTF1 + SPOTC1
POSS1	Slanted	LITE2	SPOTB2 + SPOTF2 + SPOTCZ
POSV1	Vertical	HEAVY1	SPOTC1 + SPOTR1
DEPTHU1	Unplanted	HEAVY2	SPOTCZ + SPOTR2

Table 3.--Correlation coefficients for variables significantly correlated **with survival** for the first series of plots.

Variable	District			
	Augusta	Hodge	Savannah	Hopewell
	r-value			
SPOTB1	NS	NS	0.45	0.35**
SPOTF1	-0.38**	NS	NS	-0.22**
SPOTC1	-0.50***	NS	NS	-0.24**
SPOTH1	NS	0.28**	0.29**	NS
SPOTR1	NS	NS	-0.54***	NS
SIZEN1	NS	-0.26**	NS	NS
SIZEL1	NS	0.29**	-0.21*	0.19*
POSH1	-0.79***	NS		-0.27**
POSS1	-0.60***	NS	-0.26***	NS
POSV1	0.76***	NS	0.46***	0.23**
DEPTHU1	-0.72***	NS	NS	NS
DEPTHS1	-0.54***	NS		-0.32***
DEPTHN1	0.40***	NS	0.26**	NS
DEPTHD1	NS	NS	NS	0.19*
SPOTB2	NS	NS	NS	0.19*
SPOTF2	NS	-0.26**	NS	NS
SPOTCZ	NS	NS	NS	-0.23**
SPOTH2	NS	0.33***	0.46***	0.24**
SPOTR2	NS	-0.32**	-0.51***	NS
SPOTE2	-0.41***	NS	NS	NS
SHALLOW	-0.68***	NS	-0.21*	-0.33***
LITE1	0.41***	NS	0.58***	0.28**
HEAVY1	-0.41***	NS	-0.58***	-0.28**
LITE2	0.26*	NS	0.53***	0.26**
HEAVY2	-0.26*	NS	-0.53***	-0.26**

Significance Levels:
± 10.0-14.9, * 5.0-9.9%, ** 1.0-4.9% *** under 1%

Table 4.--Variables significantly correlated with survival in each district for the second series of plots.

Variable	District: Augusta	Hodge	Savannah	Hopewell
	r-value			
SPOTB1	NS	0.35*	NS	NS
SPOTF1	NS	NS	NS	0.23**
SPOTC1	+	-0.39**	NS	NS
SPOTH1	0.25*	-0.38**	NS	-0.33***
SPOTR1	NS	NS	0.44***	NS
SPOTD1	NS	NS	-0.24*	NS
SIZES1	NS	NS	NS	-0.22*
POSH1	-0.30**	NS	-0.28**	NS
POSS1	NS	-0.45**	NS	NS
POSV1	NS	0.45**	0.28*	NS
DEPTHN1	NS	+	NS	NS
SPOTB2	NS	0.33*	NS	NS
SPOTF2	NS	NS	0.28**	NS
SPOTC2	NS	-0.38**	NS	NS
SPOTH2	N S	-0.48**	NS	NS
SPOTR2	NS	NS	0.28**	NS
SPOTE2	NS	0.43**	NS	NS
SPOTW1	NS	NS	NS	0.26**
LITE1	NS	0.34	-0.37***	NS
HEAVY1	NS	-0.34	0.37***	NS

Significance levels:
± 10.0-14.9%, * 5.0-9.9%, ** 1.0-4.9% *** under 1%

coefficients were almost identical for both survival and for the arcsin transformation, all subsequent discussion will refer to the untransferred survival percentages.

Several points in Tables 3 and 4 are of interest. First, both the number of variables and their significance levels are greater for the first series than for the second series. Second, few of the factors that are significant in the first series are significant in the second series. In fact, only about ten of these factors are significant in both series and eight of these change sign from one series to the other. This implies that any correlation is spurious at best. Only the position of the tree after it is planted was significantly correlated with survival for both series and maintained the same algebraic sign. Trees that were planted in a horizontal or slanted position did not survive as well as those planted in a vertical position. A third point to note is that the correlations are generally quite low and usually account for less than twenty percent of the variation in survival.

A model was developed to predict survival in each district by using the variables in that district that were correlated with survival and whose algebraic sign seemed to make good biological sense. Only the first series data was used and there was no attempt to find the best fitting model or to eliminate variables initially selected. Predictor variables used for each district are given in Table 5. The model was then applied to other districts and to the second series to determine if it had any predictive ability. Correlations between observed and predicted survival are given in Table 6. Note that use of a combination of variables to predict survival generally resulted in better correlations than use of a single variable. Note also that the model usually predicted poorly when applied to other districts in the same year, or to the same district in different years. When the model did predict another district reasonably well, it was only because some of the variables used in the model were significant in both districts. Models developed from the first series data were almost always unsuccessful when applied to the second series data.

These results suggest that identification of areas with good survival potential based upon appearances of that site or planting job is not as simple as it may first appear. Certainly there is a need for adequate site preparation, but what is meant by adequate site preparation and how to

Table 5.--Variables used in a multiple regression approach to predict survival.

District			
Augusta	Hodge	Savannah	Hopewell
POSV1	SPOTH1	SPOTR1	SHALLOW
POSS1*	SOZEN1*	SPOTB1	SPOTF1
SPOTC1	SIZEL1	SHALLOW	SPOTB1
SPOTF1		POSV1	HVY1
SHALLOW		SPOTH1	POSV1
HVY1		POSS1	SPOTC1

* Last variable to be significant at the ten percent level in the combined model.

measure it is uncertain. The preparation on most of the plots in the second series was characterized by Continental's field people as acceptable, but survival on those areas characterized as marginal preparation did not differ significantly. Likewise an adequate planting job would seem to be a prerequisite to achieving survival. The planting job for all of the plots in the second series was characterized as acceptable, but there was a wide range in survival.

These results put us in the uncomfortable position of assuming that good site preparation and planting techniques are important in achieving survival, but not being able to recognize or measure those attributes that make it good in the first place. Perhaps the analysis on a district level permitted the inclusion of so many different variables that any relationship between plot attributes and survival was masked.

Data from the Augusta and Savannah districts were combined and broken down into three broad site types to determine if this was indeed the case. Site types included piedmont soils, dry sites in the flatwoods and upper coastal plain, and wet sites. These two districts were chosen because they are contiguous and use similar methods of site preparation and planting. The correlation analysis was done separately for each of the three site types. Results were similar to those shown in Table 4, with the same variables being identified as being significant and having a similar r-value as that obtained when the analysis was done on a district basis.

This would suggest that appearances of the site preparation and planting job play only a minor role in identifying survival potentials. However, the analysis did identify some factors that seemed to be clearly related to survival. The planting of trees in site preparation or logging debris or the planting of sites where most of the planting spots had coarse debris close

Table 6.--Correlations between observed and predicted survival using models developed with first series data and applied to other districts to the second series.

Model Developed With Data From:	Correlations when model applied to: Augusta First	Augusta Second	Hodge First	Hodge Second	Savannah First	Savannah Second	Hopewell First	Hopewell Second
	r-value							
Augusta	0.85**	NS	NS	NS	0.64**	NS	0.64**	NS
Hodge	NS	0.33*	0.36	NS	NS	0.42**	NS	NS
Savannah	NS	NS	NS	NS	0.74**	NS	0.52**	-0.37**
Hopewell	0.41**	NS	0.23*	-0.37**	0.37	NS	0.53**	NS

to it generally had an adverse effect upon survival. Shallow planting, or planting the tree in a slanted position had a strong negative influence, particularly under conditions where environmental factors were favorable to survival. The deleterious effect of shallow planting is well recognized, but the apparent importance of tree position after planting is less well recognized. Tree position itself is probably not important but is an indicator of other factors. Plots that had high percentages of vertically planted trees tended to have an absence of coarse debris on the site,i.e., better preparation, few shallow-planted trees, and few large trees. Thus tree position is probably a sympton rather than a cause.

Perhaps the important point to note though is that all of the attributes of the tree or of the planting spot only accounted for ten to twenty percent of the variation in survival. This suggests that the reasons for planting success or failure are largely unexplained by visual impressions of the planting site or of the planting job. A reasonable explanation for this is that planting success is dictated by both primary and secondary factors. The primary factors are environmental, namely soil moisture at the time of planting and during the spring and summer of the year following planting. Secondary factors are all of the variables considered in Table 2, plus other factors such as seedling care and handling from the time the tree is lifted until it is planted. The primary factors must be at an adequate level before the secondary factors exert an influence. This line of reasoning may serve to explain why more factors were related to survival and at a higher level of significance in the first series of plot than in the second series. It is clear from the survival distributions shown in Table 1 that environmental conditions were better for survival in the first series.

Studies investigating the relationship between survival and any other factor, whether management input or conditions of the planting site, must somehow be designed to account for soil moisture levels during planting and for the first growing season after planting if the relationships being studied are not to be masked. One possibility suggested by the late Dr. Dave Moehring, is to determine water availability in the surface foot of soil using the methods of Carlson and others (1956), convert these to soil moisture tension and relate number of days with soil moisture tension below the wilting point to survival. Presumably the factors being studied could be evaluated as deviations from this relationship and may be significant at one level of soil moisture tension and not another. If something like this is not done, then any relationships observed are likely to be valid only for the year and locality in which they were observed.

Survival Trends Following The First Growing Season

There are always questions as to how soon after planting does mortality become so negligible that the plantation can be considered to have been established. A simple linear model with no intercept which predicted the number of live trees in one year based on the number present in the preceeding year was developed for each of the districts and for each series. Differences in slopes were evaluated for significance by comparing the residual sum of squares for all districts against that obtained by summing the residual sum of squares for each district.

Results of this are shown in Table 7. Generally

Table 7.--Ratio of number of live trees at any one year to the number of live trees in the preceeding year

District	Year of Comparison: Second vs. First — First Series	Second vs. First — Second Series	Third vs. Second — First Series
	ratio		
Augusta	0.948[a] 1/	0.950[a]	0.981[a]
Hodge	0.856'	0.925[a]	0.985[a]
Savannah	0.967[a]	0.952[a]	0.983[a]
Hopewell	0.939[a]	0.945[a]	0.983[a]
Combined	0.954 2/	6.947	0.983

1/ Ratios followed by the same letter do not differ significantly at the five percent level.

2/ Does not include the Hodge district.

ninety-five percent or more of the trees that have survived through the first growing season continue to survive through the second growing season, while ninety-eight **percent** of the trees that **survived through the second growing season** survived through the third growing season.

The second-year survival associated with the first series plots in the Hodge district was about ten percent lower than what had been obtained in the other **districts.** This was undoubtedly due to the very severe **summer** drought already noted. **It should be clear from this data** that if a plantation can survive through the first summer, that **it** takes an extreme climatic event to result in appreciable mortality in subsequent years.

If data from the Hodge district is not considered, second-year survival averages about 95 percent of that present after the first year, and is almost identical for each of the two series. **Separation of the second series plots for the Savannah and Augusta districts into the broad** site types mentioned previously suggests that second year survivals do not differ among the site types, **and are similar to those of the other districts.**

Results in Table **7 provide** convincing evidence that most of the mortality suffered by a plantation occurs in the spring **and summer** following planting and little additional mortality can be expected to occur in subsequent **years.** This trend may reverse itself as fusiform **infection** and other natural factors begin to **take** their toll.

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EARLY DEVELOPMENT OF LONGLEAF PINE PLANTED ON PREPARED SITES IN THE EAST GULF[1/]

Robert M. Farrar, Jr.,and John B. Whit&'

Abstract .--Up to about age 10, longleaf pine stands planted with improved techniques on prepared sites in the East Gulf are comparable in development to a successful old-field plantation and are at least 2 or 3 years ahead of well-managed naturally reproduced stands. At plantation age 7, survival was 50 percent or better, and at least 300 trees per acre were l-inch d.b.h. and larger, The planted dominant stand at age 7 was 14 to 20 feet tall, about 3 to 5 times taller than the natural dominant stand 7 years from seed fall. Suggestions for successful longleaf planting on prepared sites are also included.

INTRODUCTION

Longleaf pine (*Pinus palustris*) has a reputation of being nearly impossible to plant successfully. Many foresters-think that longleaf plantings are either doomed to less than 50 percent initial survival or, if initial survival is reasonably good, to insufficient numbers of trees emerging from the grass stage. This bad reputation is largely due to a lack of attention to the silvicultural requirements for successful longleaf planting. Longleaf cannot be treated the same as the other southern pines - the fact that the seedling has no stem should indicate this. Just as the notion that you can use the seed-tree method to regenerate natural longleaf stands has been invalid for about 20 years, the general notion that you can't successfully plant is similarly outdated. Just as properly applied shelterwood method meets the silvical requirements for natural longleaf regeneration (Croker and Boyer 1975), proper application of artificial regeneration techniques will also ensure successful longleaf planting. This is not to say that longleaf planting will be less expensive or more certain than planting other species or that longleaf will necessarily grow as fast initially as other species. However, if a manager wants to obtain the desirable traits of longleaf, the techniques necessary for good survival and rapid height-growth are now largely known.

The following data are the results from samples of a series of plantations on prepared forest sites established since 1970 by the T. R. Miller Mill Company, Brewton, Alabama. This organization has artificialy regenerated about 7,146 acres of longleaf pine, 4,120 acres of which have been planted since 1969.

METHODS

Site Preparation

Descriptions of soils and site preparation techniques are given in Table 1 for the five planting situations investigated. Generally, the soils are sandy loams to loamy sands underlain by loamy material and characteristic of the pinehills of the East Gulf Middle Coastal Plain. The topography is gently rolling and dissected by many small streams. The site index varies from about 70 to 80 feet at 50 years for natural longleaf pine stands. Sites A through C are located in Escambia County, Alabama, and sites D and E are in Santa Rosa County, Florida.

The site preparation techniques varied somewhat in the number of operations (or completeness), but two key operations appear to be: (1) clearing the site of woody vegetation, followed by (2) disking. All techniques essentially resulted in complete destruction of woody competing vegetation and removal thereby of all sources of brownspot (*Scirrhia acicola*) infection. No additional cultural treatments have been imposed on the sites.

[1/] Presented at the Southern Silvicultural Research Conference, Atlanta, GA, Nov. 4-5, 1982.

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Table 1.--Longleaf pine planting site information

Planting Location	Site Preparation 1/	First Growing Season	Soil 2/	Site Index 3/	Plot Number
				ft	
A 4/	C R W D Bd	1971	Troup fine sand	67	118 120
B	C R W D	1971	Troup fine sand	67	119
			Benndale fine sandy loam	71	121 122
C	C R Pi Br S D	1970	Orangeburg fine sandy loam	71	123 124
D	C R Pi D	1974	Orangeburg sandy loam	75	125 126 127 128
E	C R Pi D	1973	Bonifay sandy loam	65	129 130 131

1/ C = site cleared by clear-cutting, followed by shearing with a V-blade, R = soil root-raked, W = debris windrowed, D = soil disked, Bd = soil bedded, Pi = debris piled, Br = debris burned, S = burned debris scattered.

2/ Soil Conservation Service (1975, 1980).

3/ Site index classified by Soil Conservation Service (1975, 1980), index age = 50 years.

4/ Planting location approximately ranked from greatest site preparation intensity, A, to lowest, E.

Planting Stock

Planting stock was 1-0 and of good quality. Seedlings were grown at nurserybed densities of 12 or 15 per square foot and had been properly root-pruned in the nursery, 10 to 12 weeks before lifting, to promote the growth of fibrous lateral roots and prepare the seedlings for lifting. Stock had also been protected from brownspot infection and fusiform rust (Cronartium quercuum f. sp. fusiforme). Good foliage health and well-developed lateral roots are regarded by some to be more important than root-collar diameter. However, for best survival and growth, the root-collar diameter should be 0.4 inches or larger and roots should be 6 to 8 inches long.

Stock Storage

All stock was properly stored in the shade. Bales were protected against freezing, heating, and drying. They were stored one layer deep and watered every 5 days. Ideally, the seedlings were planted as soon as possible after they were lifted from the nursery bed.

Planting

All planting was done with a modified planting machine drawn by rubber-tired industrial-type tractors. Planting was not started until several weeks after site preparation had been completed. The site usually had received several soaking rains which caused desirable surface soil settling and provided adequate soil moisture at planting time. Seedling roots were not allowed to dry out while in the planting tray. The tractor proceeded at a rate slow enough so that the planter could accurately position the stemless seedlings in the slit. This operation is a "hands-on" learned skill and is most important. The planter must learn to judge the tilth of the site and position the seedlings so that about 6 months to a year later, when the site and the packing-wheel ridge have finished settling, the seedling root-collars will be at or slightly below the soil surface and the terminal bud will be exposed.

Planting rates were about 0.5 acre per hour. About 700 to 1,300 trees per acre (TPA) were planted 3 to 6 feet apart in rows about 10 feet apart.

Inventory Plots

When the plantations were 4 to 5 years old, 14 semi-permanent 0.1- to 0.2-acre rectangular plots were installed. All trees on these plots were positively identified. Although these plots represent reasonably successful plantations, they were selected to cover the available range of planting situations and stand densities, were limited in number, and may not represent average conditions for each situation. The following data were recorded.

(a) plot number and location information.
(b) plot dimensions, size, and planting spacing.
(c) site preparation information.
(d) a tally of all living stems; d.b.h. measured to 0.1-inch.
(e) a systematic sample of one-third of the trees in each 1-inch d.b.h. class for total height. All of the sample trees in the dominant stand (dominants and codominants) were bored at a 4-foot height to obtain a ring count.
(f) stand age from planting, average ring count and average height of dominant stand sample trees, and current number of TPA.

The plots were inventoried on a 3-year cycle. The data were summarized after each inventory on a per-acre basis as number of trees, height, basal area, and cubic-foot volume (Farrar 1981) per 1-inch d.b.h. class and per stand. These data were combined and averaged by planting location (Table 2).

Natural Stand Plots

For comparison, data were taken from a natural stand spacing study in which three permanent, circular 0.2 acre plots were established in each of five residual densities varying from 300 to 1,500 TPA when the trees were 7 years old from overstory release (9 years from seed fall) (Farrar 1974). From this study, the data from nine plots representing densities of 1,200, 900, and 600 TPA were summarized at ages 7, 9, and 11 years after release. This group of plots was chosen because its residual total TPA was similar to the planted TPA and the development of its stand 1-inch d.b.h. and larger was relatively uniform. The study site contains soil similar to the plantations and has a site index varying from 70 to 80 feet at 50 years for natural stands. The seedlings came largely from the fairly good seed crop of 1958 (Croker and Boyer 1975) on a seed-tree stand (about 10 TPA). After two growing seasons the parent trees were removed in 1961. In 1967, 7 years after overstory release, the spacing study was installed by precommercial thinning. All hardwoods were killed at the time of study installation and plots have been winter-burned by prescription on a 2-year cycle starting in the winter of 1973-74.

Inventory and summary techniques are essentially the same as those in the plantation plots, except that the sample-tree frequency was 1/6. These plots have been inventoried on a 2-year cycle and their data are summarized on a per-acre basis in Table 3.

RESULTS AND DISCUSSION

Survival

Survival has been 50 percent or better for all planting situations through ages 10 and 11 (Figure 1). There is a general trend for survival to increase with each successive planting and this is attributed to concurrent improvements in site preparation and planting technique. Although all preparation was intensive, site C has a heavier and moister soil relative to the other sites which resulted in a rougher planting surface and more vegetative competition. This condition plus initial lack of planting experience are thought to have contributed to the poorer survival of this site. The other planting sites were relatively smooth.

Survival in the natural stand was essentially 100 percent 7 to 11 years after overstory release (9 to 13 years after seed fall). All of these trees were well-established when the spacing treatments were imposed at age 7 from release.

Trees Per Acre

While the trend in survival of total planted TPA was gradually downward after the initial losses (Figure 1), the trend in percent of TPA 1-inch d.b.h. and larger was sharply upward for the first period (Figure 2), followed by a slower increase. By age 10 or 11, the proportion of the trees 1-inch d.b.h. or larger was at least 95 percent in the three older plantations and a

Table 2.--Longleaf plantation development summary 1/

Planting Location	First Growing Season	Age from Planting	TPA Planted	Years in Grass	HD	TS0	TS1	B1	V1	TS4	B4	V43	Number of Plots
		yrs	no	yrs	ft	no	no	ft²	ft³	no	ft²	ft³	
A	1971	0	1132	3	--	--	--	--	--	--	--	--	2
		4			8	755	550	6	23	0	0	0	
		7			20	730	720	29	219	30	3	17	
		10			29	725	720	46	541	290	28	285	
B	1971	0	1225	3	--	--	--	--	--	--	--	--	3
		4			6	890	530	2	9	0	0	0	
		7			17	847	753	24	170	30	3	18	
		10			26	823	780	42	451	243	22	213	
C	1970	0	1271	4	--	--	--	--	--	--	--	--	2
		5			7	670	320	3	10	0	0	0	
		8			18	655	560	19	127	15	2	a	
		11			27	640	605	39	418	270	26	236	
D	1974	0	612	3	--	--	--	--	--	--	--	--	4
		4			7	463	198	2	6	0	0	0	
		7			16	457	412	13	83	0	0	0	
E	1973	0	672	3	--	--	--	--	--	--	--	--	3
		5			a	402	241	3	11	0	0	0	
		8			18	393	343	14	108	35	3	20	

1/ Term Legend: TPA = trees per acre; Years in grass = age from planting - (avg. ring count @ 4' for D & CD trees); HD = dominant stand height; TS0 = TPA surviving, all trees; TS1 = TPA surviving, trees 1" d.b.h. & larger; B1 = basal area for TS1; V1 = total cubic-foot volume, i.b., for TS1; TS4 = TPA surviving, trees 4" d.b.h. 6 larger; B4 = basal area for TS4; V43 = cubic-foot volume, i.b., to a 3" d.o.b. top for TS4.

Table 3.--Longleaf natural stand development summary 1/

Age from Release	Years in Grass	HD	TS0	TS1	B1	V1	TS4	B4	V43	Number of 1/5-acre Plots
yrs	yrs	ft	no	no	ft²	ft³	no	ft²	ft³	
2	7		6000	—	—	—	—	—	—	9
7		9	900	372	4	18	0	0	0	
9		16	897	629	16	97	11	1	6	
11		23	891	797	31	256	125	11	81	

1/ Term Legend: same as Table 2 except Years in grass = age from seed - (avg. ring count @ 4' for D & CD trees)

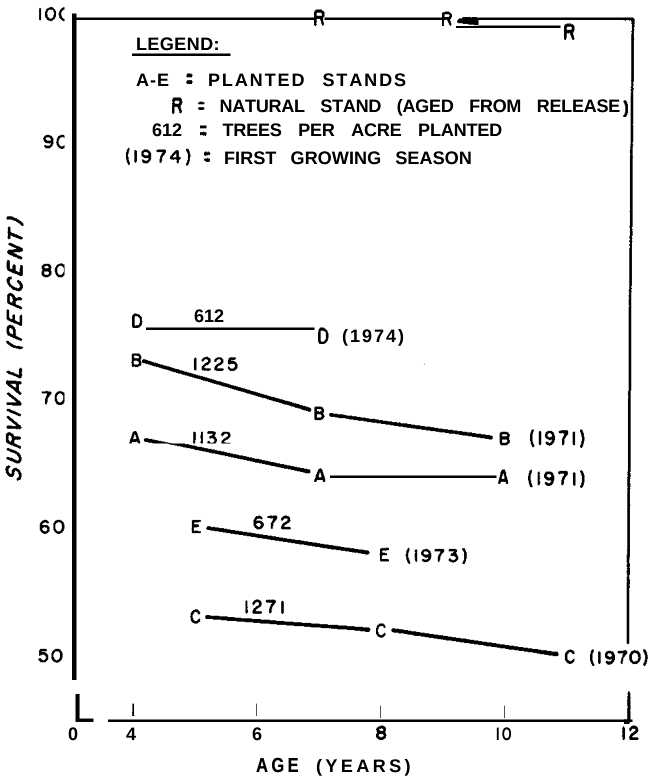

Figure 1.--Survival of longleaf pine in planted and natural stands.

similar proportion is suggested for the two younger plantations when they reach this age. The natural stand shows a lag in development; only about 90 percent of the stand was l-inch d.b.h. and larger by 11 years after release (13 years after seed fall).

It is interesting that these results independently confirm the finding of Croker and Boyer (1965) that natural seedling stands released from parent over-stories at age 2 will have about 41 percent of the seedlings in height-growth (over 0.5-foot tall) 7 years after release. Here we had at least 41 percent of the natural stand taller than 4½ feet 7 years after release.

Merchantable stand development (trees 4-inches d.b.h. and larger) shows a different pattern. In plantations and natural stands, the increase during the first growth period is gradual followed by a sharp increase in the second period. Ten or 11 years after planting the plantations had 30 to 40 percent of their trees 4-inches d.b.h. or larger, while in the natural stand only 14 percent were this large 11 years after release.

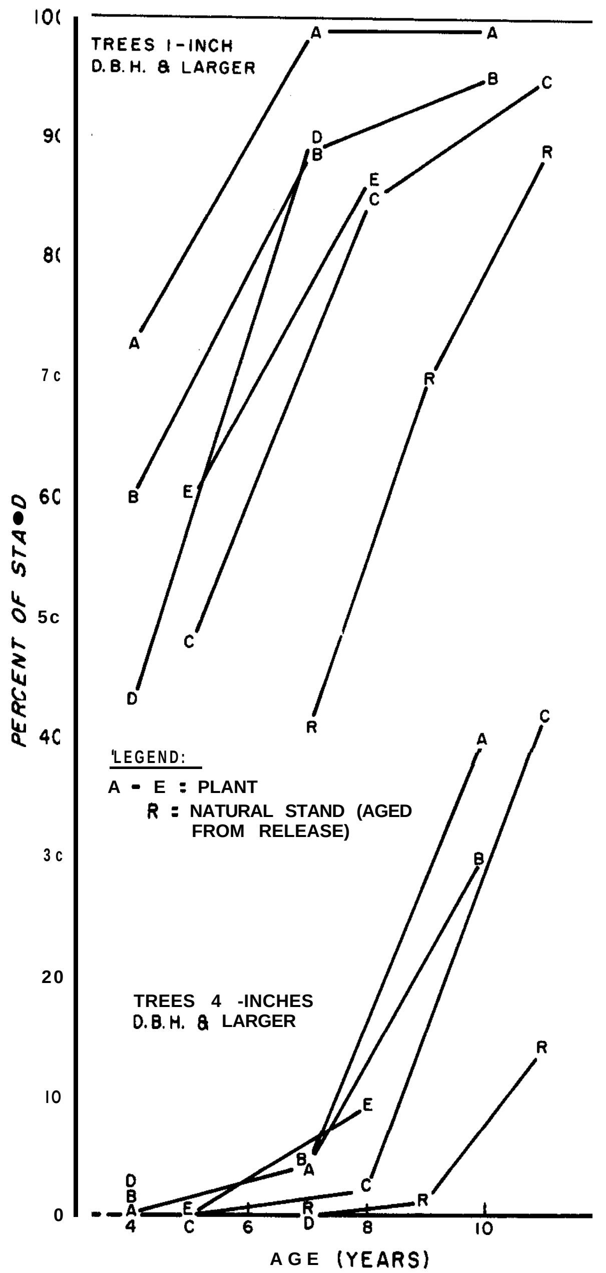

Figure 2.--Proportion of longleaf pine stems equal to and larger than 1- and 4-inches d.b.h. in planted and natural stands.

In absolute numbers, all plantations had at least 300 TPA l-inch d.b.h. and larger, 4 to 7 years after planting (Figure 3). By age 10 or 11 the three older plantations had from about 600 to nearly 800 TPA this large. The natural stand had 350 TPA this large 7 years after release and almost 800 four years later. The three older plantations had from 243 to 290 TPA 4-inches d.b.h. and larger 10 or 11 years after planting while the natural stand had only 125 such TPA 11 years after release. In the merchantable TPA component, the natural stand appears to lag behind the planted stands by at least 2 to 3 years.

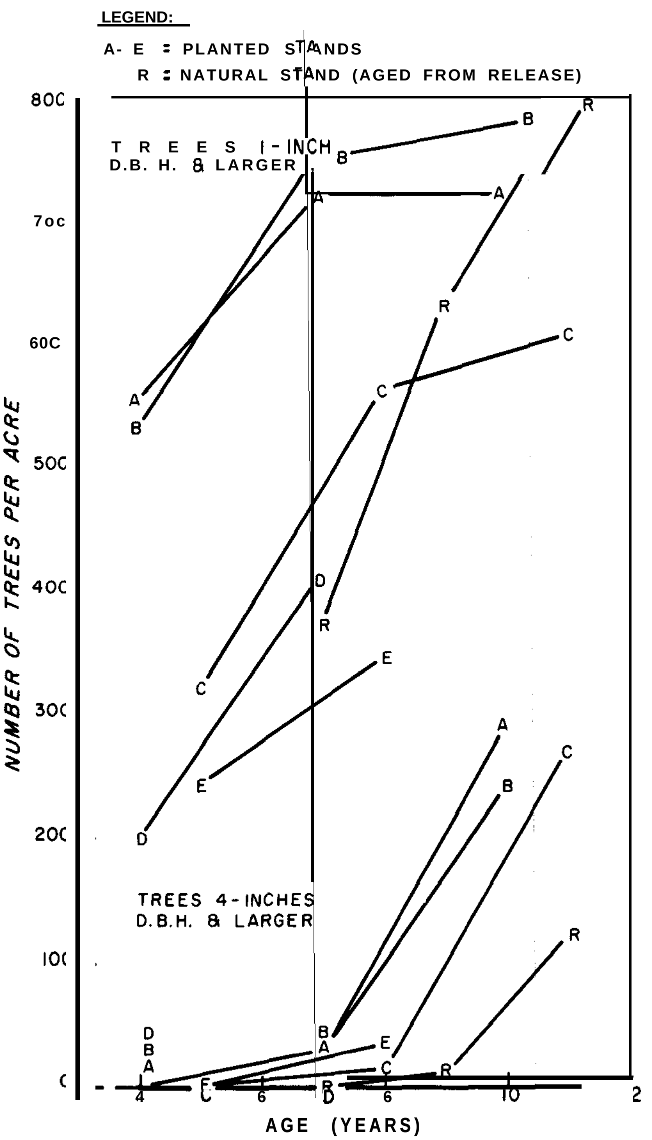

Figure 3.--Number of longleaf pine trees per acre equal to and larger than l- and 4-inches d.b.h. in planted and natural stands.

Dominant Stand Height

The dominant stand in all plantations had grown to over 4% feet 4 to 5 years after planting and by age 7 they were 14 to 20 feet tall (Figure 4). Note that it is standard practice to assume that dominant natural longleaf stands are over 4% feet tall 8 years after seed fall (Forest Service 1976). In several studies on medium sites, where the age of the natural reproduction from seed-tree and shelterwood stands was known and the reproduction had been reasonably well managed, we have found this to be generally true. In the natural stand spacing study we knew that most of the reproduction came from the 1958 seed crop. In 1967 most of the dominant stand trees showed 2 rings on cores taken at a height of 4 feet, indicating that they were somewhat less than 4 feet tall 7 years after seed fall (5 years after release). The plantations were at least 3 to 5 times this tall 7 years after planting. The natural stand reached heights of 14 and 20 feet about 8 and 10 years, respectively, after release. Again, the natural stand appears to lag behind the plantations by at least about 2 to 3 years.

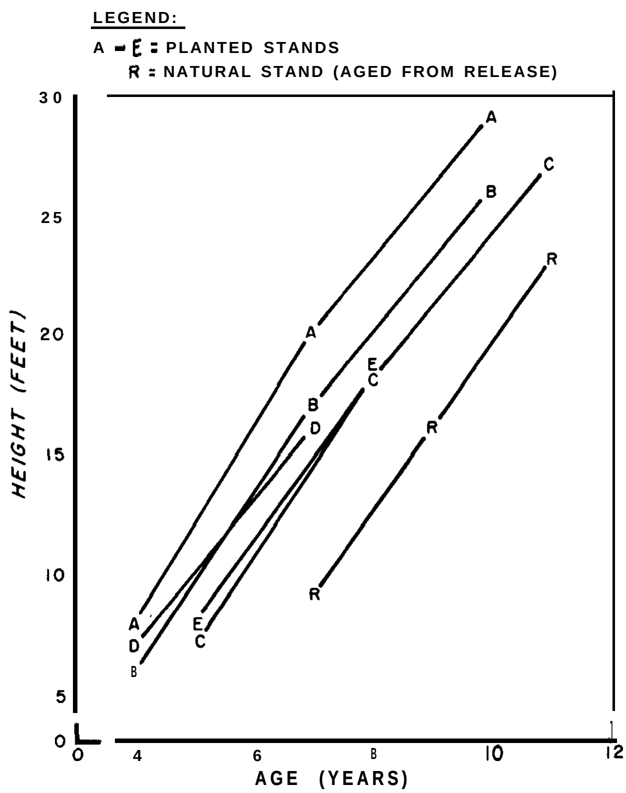

Figure 4.--Longleaf pine dominant stand height development in planted and natural stands.

Volume

Total and merchantable cubic-foot volumes, i.b., are presented in Figures 5 and 6. The three older planted stands had produced between 420 and 540 total cubic feet 10 or 11 years after planting. The natural stands had produced only about 250 total cubic feet 11 years after release. The plantation merchantable volumes (d.b.h. >3.5 inches, 3-inches d.o.b., top) varied from 215 to 285 cubic feet 10 or 11 years after planting. Assuming 80 cubic feet, i.b., per rough cord, this amounts to between 2.7 and 3.6 cords. The natural stand produced about 80 cubic feet, or 1 cord, 11 years after release. In volume production too, the natural stand appears to lag behind the planted stands by at least 2 to 3 years.

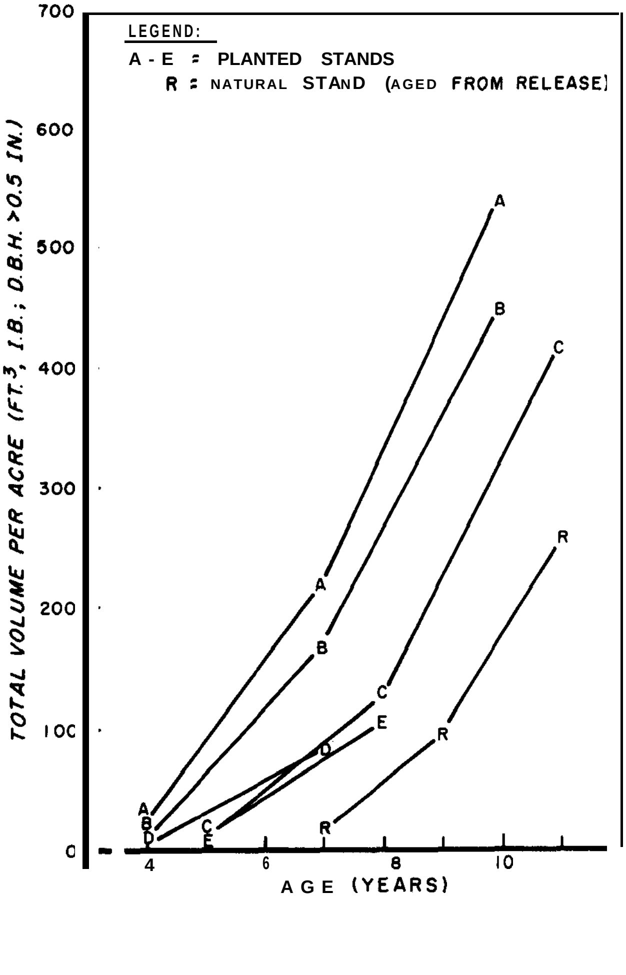

Figure 5. --Early longleaf pine total volume production in planted and natural stands.

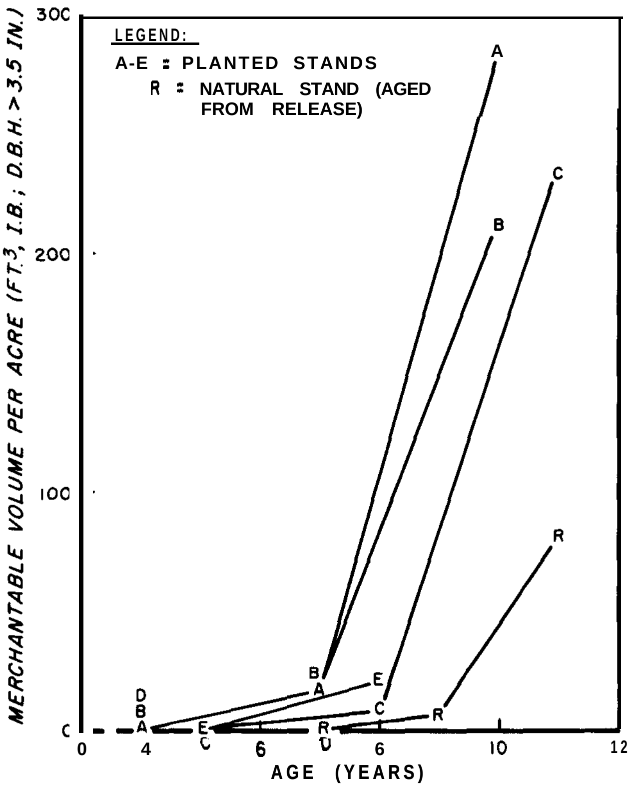

Figure 6.--Early longleaf pine merchantable volume production in planted and natural stands.

In comparison, production to age 10 for a well-tended stand planted on an old-field in South Alabama varied mostly from about 3 to 6 cords for densities of 600 to 800 current total TPA with some denser portions reaching about 11 cords (Farrar 1974). The proposition that these levels of production would be near the maximum expected from plantations on old-field or intensively prepared sites is supported by the plantation yields of this study.

SUGGESTED PRACTICES FOR PLANTING LONGLEAF PINE ON PREPARED SITES

The following brief outline of requirements for successful planting of longleaf pine results from observations of successful plantings, discussions with successful planters, and direct experience in planting longleaf on sandy prepared sites in the Middle Coastal Plain of the East Gulf. It is not intended to cover all the details.

I. Use good planting stock (better stock = better start)
   A. Grow at low nursery bed density - 12 to 15 per square foot.
   B. Stock must be vigorous - at least 0.4-inch at the root collar (White 1979) (0.5-inch is better) - and well protected in the nursery from brownspot and fusiform rust.
   C. Stock should be properly root-pruned 10 to 12 weeks prior to lifting to prepare seedlings for lifting and outplanting and to promote development of fibrous lateral roots which may promote survival (Brown 1964). Roots should be 6 to 8 inches long.

II. Handle stock properly (don't kill 'em before they're planted)
   A. Planting as soon after lifting as possible is best.
   B. Protect seedlings from drying, heating, and freezing when storing or planting. Temporarily store bales in the shade and in layers 1 bale deep.
   C. Use cold storage if seedlings cannot be planted within 1 week. If left in cold storage beyond 2 weeks, discard seedlings with root-collar diameter less than 0.5-inch.

III. Employ good site preparation (the more complete, the better)
   A. Destroy all competing woody and grassy vegetation with as little topsoil loss as possible. Mechanical preparation should be completed before July to reduce sprouting by woody stumps.
   B. Destroy all residual longleaf pines on the planting site, since these are sources of brownspot infection.
   C. Allow soil on the site to settle for several months; a few soaking rains should occur before planting.
   D. The soil surface should be relatively smooth; rough planting sites result in more poorly positioned seedlings.

IV. Use good planting techniques (planter skill must be developed)
   A. Plant only-when soil moisture is adequate.
   B. Plant on contour to lessen chance of soil erosion.
   C. Plant more slowly and carefully than with other southern pines.
   D. Position seedlings when planting such that 6 months to a year after planting, when the soil on the site has fully settled, the seedling bud will be exposed. This calls for initially positioning the seedling bud somewhat below the soil surface (and packing-wheel ridge) but the amount depends upon planter experience with soil tilth on the planting site and the amount of soil settling anticipated after planting. The seedling root should never be exposed.
   E. If machine planting, a planting machine drawn by an industrial wheeled tractor is recommended. Several machines are available, some perhaps are better than others.
   F. Initially, plant at a 3-foot spacing in rows 10 feet apart. As successful experience is gained, the spacing can be increased to, say, 6 by 10 feet. Don't worry about planting too many seedlings. They are the cheapest part of the entire operation. Don't worry about stagnation if they all survive (unlikely) - longleaf breaks early and strongly into crown classes and has less need for precommercial thinning than other southern pines.

V. Protect and monitor the plantation
   A. Protect seedlings from cattle. Cattle trample seedlings and can cause unacceptable losses. Also, they can aggravate a situation where brownspot is a problem by closely grazing the site and preventing enough fuel accumulation to carry a brownspot burn.
   B. Make annual checks for brownspot and burning needs for brush control until a minimum of 300 trees per acre are in height growth.

CONCLUSION

From the data presented it is obvious that longleaf pine can be successfully machine-planted on prepared sandy sites in the East Gulf Middle Coastal Plain on an operational basis. All five planting situations had stands that averaged better than 50 percent survival at age 10 and more than

300 TPA were l-inch d.b.h. and larger 7 years after planting. The height of the dominant stand 7 years after planting was at least 3 to 5 times the height of a natural stand 7 years after seed fall. Plantation volume production was much better at given ages from planting (or release) than a comparably stocked naturally regenerated stand under good management and comparable to a local well-tended old-field plantation. Employment of the suggestions presented for planting **longleaf** pine should largely ensure establishment of successful plantations on prepared sites.

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EFFECTS OF INITIAL SEEDLING DENSITY ON SPOT-SEEDED LOBLOLLY AND SLASH PINES AT AGE 15 YEARS [1/]

Thomas E. Campbell [2/]

Abstract.--Early thinning of multiple-seedling spots to a single stem provided adequate stocking and increased growth by age 15. Leaving 2, 5, or 9 seedlings per spot caused a significant reduction in height and diameter growth for most of the species-density-site combinations. This suggests a change in currently recommended spot sowing rates to reduce clustering.

INTRODUCTION

Direct seeding is a successful and widely accepted method of regenerating southern pines. Aerial seeding is generally used on large areas, but spot sowing by hand is an excellent alternative for small tracts or where broadcasting is impractical. Spot seeding requires only one-third to one-fourth the seeds used in broadcast sowing, and permits more precise control of stocking and spacing than is possible with broadcasting. It is also cheaper, faster, and less laborious than hand planting nursery seedlings. Spot seeding is especially suitable for the small landowner who must keep out-of-pocket expenses to a minimum.

In spot seeding, multiple seeds are dropped on a spot to insure at least one seedling. Mann and Burns (1965) recommended sowing six seeds per spot on 1,000 spots per acre. Though this often results in several seedlings on the spot, Campbell (1964) reported that slash pine (*Pinus elliottii*) showed no adverse effects from such clustering at age 3.

This study was established in 1962 to determine how many seedlings were needed on a spot to insure adequate stocking, and to determine the effect of multiple trees per spot on growth to merchantability. Loblolly (*P. taeda* L.) and slash pines were established at a rate of 1,000 spots per acre at densities of 1, 2, 5, and 9 seedlings per spot. All species-density combinations were installed on each of two sites. Site index was not determined.

Lohrey (1970) reported measurements of the study at age 5. Spot density did not affect height growth of the tallest tree per spot, and the tallest trees were maintaining dominant crown positions on most spots at all densities. Many small trees were expected to drop out of competition rapidly after crown closure. By age 10, Campbell (1981) found that 1 or 2 seedlingsper spot produced fully stocked stands of both species on both sites; 5 and 9 seedlings per spot showed a slight reduction in height and diameter growth.

This paper reports measurements of the study at age 15.

METHODS

Initially, four seedling densities were established on 0.l-acre square plots and were replicated four times in a randomized block design for each species on each of two sites. Experimental design did not permit statistical comparison of species or sites.

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On site A, initially classified as being medium in quality, topsoil was a brown fine sandy loam 8 inches deep that overlaid a red sandy clay loam subsoil. Surface and internal drainage were good. Site B was the poorer of the two sites; it had a gray sandy loam topsoil about 6 inches deep underlain by a slowly permeable reddish brown clay. Surface drainage was adequate. Scattered second-growth longleaf pines and numerous scrub hardwoods covered both sites. The pines were felled and removed and hardwoods were injected with herbicides before the study was installed.

Seed spots were prepared at 6.6-foot square spacings (1,000 per acre or 100 per plot) by scraping leaves and duff away with a fire rake to expose mineral soil. Spots were hand-sown with approximately 20 stratified, repellent-treated seeds to insure heavy stocking. After two complete growing seasons, spots were thinned to their assigned densities, leaving the tallest seedlings per spot. Although poor germination and early survival resulted in average stocking below assigned densities of 1, 2, 5, and 9 seedlings per spot (tables 1 and 6), the assigned density designations will be used in this report.

The interior 25 spots on each treatment plot were used for 15-year measurements. Total tree counts were made on each spot, and d.b.h. of each tree was measured to the nearest 0.1-inch with a diameter tape. After all trees on a plot were measured, one sample tree was then selected for every three trees per l-inch d.b.h. class (0.6 to 1.5, 1.6 to 2.5, etc.). Sample trees were selected as near as possible to the midpoint of each class without regard for tree quality. All sample trees were measured with a relaskop for total height, height to the first live limb, and for successive 2-inch diameter taper steps from a 4-inch top outside bark to a l-foot stump. Relative crown position was determined for each sample tree. All dominant and codominant sample trees were used to determine site index; where needed, nonsample dominants and codominants were measured to total height only so that a minimum of 10 were available for site index determinations. The height accumulation and plot summary programs, described by Lohrey and Dell (1969), were used to compute volumes and other pertinent data.

All measurement parameters for each species on each site were tested by ANOV (0.05 level) for differences between spot densities. Duncan's Multiple Range Test was used to locate significant differences.

Trees are divided into three arbitrary size classifications in the following presentations: all trees; merchantable trees, those 3.6 inches d.b.h. and larger; and crop trees, those 5.6 inches d.b.h. and larger.

RESULTS

Loblolly Pine

At age 15, the average number of trees per multiple-stocked spot ranged from 1.3 per P-tree spot on site A to 2.4 per 9-tree spot on site B (table 1). All treatments resulted in excellent stocking; the range was from 640 to 910 stocked spots per acre. Starting with more than one seedling per spot did not significantly increase stocking on either site.

Total trees per acre on multiple-stocked spots ranged up to 1,970 on site A and 2,150 on site B. Single-tree spots had 740 trees per acre on site A and 640 on site B. Site A had 690 merchantable trees on single-tree spots and 960 on 5-tree spots. Merchantable trees on site B were slightly less in number for each density level, but the minimum was 560 trees per acre. There were no statistical differences between density levels for either site. However, the influence of initial spot density was more obvious in crop trees, the number that had grown to more than 5.5 inches d.b.h. Generally, as original spot density increased, the number of crop trees per acre decreased. Exceptions were for 2-tree spots on site A and 5-tree spots on site B.

Total heights of all trees averaged from 36 feet for 9-tree spots to 45 feet for single trees; both extremes were on site B (table 2). The significant differences are probably a reflection of spot density effects. On site A, heights of dominants and codominants were 3 to 7 feet taller than averages for all trees; site B differences were 2 to 7 feet. The only statistical difference in heights of dominants and codominants by spot density level was between 1- and 9-tree spots on site B. The proportions of total heights occupied by live crowns ranged from 32 to 44 percent for all trees, and from 36 to 49 percent for dominants and codominants. There was only one, significant difference in live crown ratios for the two groups of trees on the two sites--all trees for the 5-tree treatment on site B had shorter crowns than trees on the 1- and 2-tree spots.

Table 1.--Mean stand and stocking data at age 15 for loblolly pine

Assigned spot density	Mean density at age 2 yrs.	Current mean density	Current trees per stocked spot	Spots/acre stocked with: 1 or more trees	Spots/acre stocked with: 2 or more trees	Trees per acre: All trees	Trees per acre: Merchantable trees	Trees per acre: Crop trees
				Site A				
1	0.9	0.7	1.0	740a 1/	--	740c	690a	350a
2	1.6	1.0	1.3	720a	260	980bc	840a	360a
5	4.4	2.0	2.1	910a	670a	1,970a	960a	180b
9	6.9	1.4	1.9	730a	490ab	1,420ab	870a	180b
				Site B				
1	0.8	0.6	1.0	640a	--	640b	560a	340a
2	1.4	1.0	1.4	730a	320b	1,050b	670a	230ab
5	3.4	1.7	2.0	840a	580a	1,740a	870a	310a
9	6.0	2.1	2.4	870a	660a	2,150a	790a	100b

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable because of statistical design.

Table 2.--Mean total heights and live-crown ratios at age 15 for loblolly pine

Assigned spot density	Total height: All trees	Total height: Dominants and codominants	Live crown ratio: All trees	Live crown ratio: Dominants and codominants
	Feet		Percent	
		Site A		
1	44a 1/	47a	40a	44a
2	43a	48a	38a	45a
5	38b	45a	32b	36a
9	41ab	47a	34ab	43a
		Site B		
1	45a	47a	44a	44a
2	40b	44ab	42a	49a
5	38bc	45ab	38a	47a
9	36c	42b	36a	44a

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Site6 are not statistically comparable.

Mean d.b.h. of all site A trees on 1- and 2-tree spots was statistically greater than trees on spots with higher densities (table 3). For dominants and codominants, however, only the 5-tree spots had smaller trees. On site B, single trees were larger than those on all three other treatments for all trees; dominant and codominant single trees were also larger than those on 5- and 9-tree spots. Merchantable trees showed the same general trend as all trees--size decreased as spot density increased, and differences between density levels were significant for both sites. However, d.b.h. differences between spot densities for crop trees were not significant on either site.

The distributions of trees by l-inch d.b.h. classes for loblolly pine on both sites are shown in table 4.

Basal area for all trees and for merchantable. trees was not affected by spot density on either site (table 3). But for site A trees 5.6 inches d.b.h. and larger, the 1- and 2-tree spots had significantly more basal area than did the denser spots. On site B the only significant difference was between single-tree and 9-tree spots.

Original spot density had no statistical influence on total or merchantable volume yields for either site, though site A had slightly higher volumes than site B for each density level (table 5). But the most interesting figures in volume yields are those of non-merchantable wood by spot density classes. At age 15, about 15 percent of the total volume on single-tree spots was non-merchantable. But that proportion of non-merchantable wood increased as spot density increased to about 44 percent on 9-tree spots.

Volumes in crop trees--5.6 inches and larger--on site A S-tree spots were significantly less than on 1- and 2-tree spots, but not less than on 9-tree spots. On site B, single-tree spots had more volume than 2- or 9-tree spots, but not more than 5-tree spots. The differences clearly express the influence that multiple-trees on a spot have on volume growth through 15 years.

Table 3.--Mean d.b.h. and basal area at age 15 for loblolly pine

Assigned spot density	D.b.h.: All trees	D.b.h.: Dom. and codoms.	D.b.h.: Merchantable trees	D.b.h.: Crop trees	Basal area: All trees	Basal area: Merchantable trees	Basal area: Crop trees
	Inches				Square feet		
				Site A			
1	5.8a 1/	6.5a	6.0a	6.8a	135a	133a	91a
2	5.2a	6.8a	5.6ab	6.7a	148a	142a	89a
5	4.0b	5.0b	4.8c	6.1a	159a	122a	38b
9	4.4b	6.0a	5.1bc	7.2a	146a	119a	49b
				Site B			
1	6.0a	6.5a	6.3a	7.1a	123a	120a	95a
2	4.6b	6.0ab	5.4ab	6.8a	122a	108a	55ab
5	4.1bc	5.5bc	5.2b	6.3a	160a	128a	67ab
9	3.5c	5.0c	4.8b	6.4a	138a	98a	23b

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable.

Table 4.--Mean distribution of trees per acre by l-inch d.b.h. classes at age 15 for loblolly pine

Assigned spot density	D.b.h. classes 1	2	3	4	5	6	7	8	9	10
	-----	-----	-----	-----	Number	-----	-----	-----	-----	-----
					Site A					
1	0	0	50	120	220	160	100	70	20	0
2	10	50	80	270	210	220	60	70	0	10
5	70	410	530	490	290	130	40	10	0	0
9	0	130	470	360	280	60	60	50	10	0
					Site B					
1	0	20	60	100	120	120	100	90	30	0
2	60	130	190	190	250	140	60	10	20	0
5	70	340	460	350	210	220	90	0	0	0
9	330	540	490	380	310	70	20	10	0	0

Table 5.--Mean volumes per acre (outside bark) at age 15 for loblolly pine

Assigned spot density	All trees to the terminal bud	Merchantable trees to a 4-inch top	Crop trees to a 4-inch top
	-----	Cords	-----
		Site A	
1	35.5a 1/	30.3a	23.0a
2	39.0a	32.1a	23.0a
5	40.7a	24.8a	10.6b
9	39.3a	26.7a	13.2ab
		Site B	
1	28.2a	23.6a	20.0a
2	28.1a	20.0a	9.4bc
5	37.0a	22.8a	14.8ab
9	35.1a	15.6a	4.8c

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable.

Slash Pine

The average number of trees per stocked spot ranged from 1.0 on single-tree spots to 2.9 on 9-tree spots for both sites (table 6). Stocked spots per acre averaged 680 to 950 on site A, and from 560 to 850 on site B. Though spots with multiple trees had significantly more stocked spots per acre, the lowest 560 stocked single-tree spots were satisfactory.

Total trees per acre for multiple-stocked spots averaged up to 2,840 on site A and 2,600 on site B. This is too many trees at age 15 years for optimum diameter growth and is reflected in the proportion of trees growing into merchantable and crop size. On site A, 94 percent of the single trees had grown to merchantability and 65 percent had reached 5.6 inches or larger. For the 9-tree spots, the proportions were 33 and 2 percent for merchantable and crop trees. The same relative percentages on site B were considerably less except that 4 percent of the trees on 9-tree spots had grown to crop size. On both sites, as original density increased the number of crop trees decreased, but the rate of decrease was greater on the better site.

Mean total height of all trees was strongly influenced by spot density on site A; single trees averaged 11 feet taller than those on 9-tree spots (table 7). Dominants and codominants were only 2 feet taller than all trees on single-tree spots, but the difference was 7 feet for 5- and 9-tree spots. Density had no statistical influence on height growth at site B. Maximum differences were 3 feet for all trees and 2 feet for dominants and codominants.. It is interesting, however. that for all trees and for dominants and codominants, single trees on the better site were 9 feet taller than those on the poorer site, while trees on 9-tree spots were about equal in height on both sites.

The live crown to total height ratio for all single trees was significantly greater than for all trees on 5- and 9-tree spots on site A (table 7). But live crown ratios were not affected by spot density for all'trees on site B, or for dominants and codominants on either site.

Average d.b.h. of all trees and of merchantable trees on site A decreased significantly for each increase in spot density, but crop trees were unaffected (table 8). Mean d.b.h. on site B was influenced by spot density for all trees only. Diameters on site A were generally greater than those on site B for the three lightest densities, but the reverse was true on 9-tree spots for dominants and codominants, merchantable trees, and crop trees. Diameter distributions by l-inch classes are shown in table 9 for both sites.

Total basal area on both sites was greater for 5- and 9-tree spots than for single trees. Merchantable basal area on site A 9-tree spots was less than the other three densities, but it was not statistically influenced by spot density on site B. As with mean diameters and numbers of trees, average basal areas on site B were generally less than on the better site.

Total volume on site A was not statistically influenced by spot density, but merchantable and crop tree volumes were; exactly the opposite was true on site B (table 10). On site A, 5-tree spots had the most total volume, 2-tree spots the most merchantable volume, and single trees had the most crop tree volume. On B the 9-tree spots had the most total volume, 5-tree spots the most merchantable volume, and single trees had the most crop tree volume.

DISCUSSION

Thinning 1,000 multiple-stocked spots per acre to a single seedling per spot at age 2 was fully successful in establishing an adequate stand. A fully-stocked stand is considered to be 500 to 750 well spaced trees per acre, and all four single-tree stocking averages exceeded the minimum. As spot density was increased from one to nine seedlings per spot, however, the number of seedlings per acre also increased, and these additional seedlings were in excess of the needs. They were, in fact, detrimental to growth on the clustered spots. Average heights between 1- and 9-tree spots were significantly decreased on two species-site combinations, and average diameters were decreased on all four combinations. Total volumes were increased by the higher density, but volumes on single-tree plots were concentrated in fewer and larger trees. For example, on site A, single slash pines had about 24 trees per cord and 9-tree spots had 177 trees per cord, while on site B, there were 55 and 202 trees per cord, respectively. Starting with two seedlings per spot was also detrimental to growth when compared with single trees, but the differences were not nearly so great as between one and nine seedlings.

Table 6.--Mean stand and stocking data at age 15 for slash pine

Assigned spot density	Mean density at age 2 yrs.	Current mean density	Current trees per stocked spot	Spots/acre stocked with; 1 or more trees	2 or more trees	Trees per acre: All trees	Merchantable trees	Crop trees
				Site A				
1	0.9	0.7	1.0	680b [1/]	--	680d	640b	440a
2	1.8	1.3	1.4	860a	350c	1,270c	950a	340a
5	4.7	2.1	2.3	920a	710b	2,120b	1,020a	150b
9	7.5	2.8	2.9	950a	840a	2,840a	930a	70b
				Site B				
1	0.9	0.6	1.0	560b	--	560c	380a	160a
2	1.6	0.9	1.4	670b	260b	930bc	520a	130a
5	4.0	1.7	2.0	840a	480a	1,680b	690a	120a
9	5.6	2.6	2.9	850a	640a	2,600a	660a	110a

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable.

Table 7.--Mean total heights and live-crown ratios at age 15 for slash pine

Assigned spot density	Total height: All trees	Total height: Dominants and codominants	Live-crown ratio: All trees	Live-crown ratio: Dominants and codominants
	Feet		Percent	
		Site A		
1	43a [1/]	45a	42a	44a
2	40b	44ab	36ab	42a
5	36c	43b	33b	42a
9	32d	39c	35b	40a
		Site B		
1	34a	36a	49a	51a
2	35a	38a	42a	47a
5	32a	37a	44a	49a
9	32a	38a	42a	47a

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable.

Table 8.--Mean d.b.h. and basal area at age 15 for slash pine

Assigned spot density	D.b.h. All trees	D.b.h. Dom. and codoms.	D.b.h. Merchantable trees	D.b.h. Crop trees	Basal area All trees	Basal area Merchantable trees	Basal area Crop trees
	---Inches---				---Square feet---		
Site A							
1	6.0a[1]	6.6a	6.1a	6.6a	134b	133a	106a
2	4.7b	5.7b	5.3b	6.2a	157ab	145a	71b
5	3.8c	5.7b	4.8c	6.4a	172a	129a	34c
9	3.3d	4.5c	4.4d	5.8a	165a	101b	13c
Site B							
1	4.6a	5.2a	5.2a	5.9a	65b	56a	31a
2	4.2ab	5.2a	5.1a	6.2a	89ab	72a	27a
5	3.5bc	4.9a	4.7a	5.9a	115a	84a	23a
9	3.1c	5.0a	4.7a	6.1a	130a	81a	23a

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable.

Table 9.--Mean distribution of trees per acre by l-inch d.b.h. classes at age 15 for slash pine

Assigned spot density	1	2	3	4	5	6	7	8	9	10
Site A										
1	0	0	30	40	160	250	150	40	0	10
2	50	80	190	280	330	280	50	10	0	0
5	70	390	640	580	290	100	40	10	0	0
9	240	800	870	590	270	70	0	0	0	0
Site B										
1	0	40	140	120	100	140	20	0	0	0
2	20	150	240	190	200	110	20	0	0	0
5	210	350	430	340	230	110	10	0	0	0
9	730	680	530	350	200	100	10	0	0	0

Table 10.--Mean volumes per acre (outside bark) at age 15 for slash pine

Assigned spot density	All trees to the terminal bud	Merchantable trees to a 4-inch top	Crop trees to a 4-inch top
	---------------------------Cords---------------------------		
		Site A	
1	32.9a 1/	28.8a	23.8a
2	40.8a	31.7a	17.9a
5	41.3a	24.0ab	8.5b
9	37.2a	16.0b	2.8b
		Site B	
1	14.3b	10.2a	7.0a
2	18.5ab	12.7a	6.0a
5	24.2ab	13.1a	4.9a
9	27.0a	12.9a	4.8a

1/ For each site, means in each column followed by the same letter are not significantly different (0.05 level). Sites are not statistically comparable.

These data indicate that the initial number of seedlings on a spot is highly critical. Thus the number of seeds sown on a spot is most important. Current recommendations for southern pines are to sow five seeds per spot on 1,000 spots per acre. Long-term experience has shown that one seedling normally results from each three to four seeds sown. Five seeds per spot is good insurance for a high proportion of the spots to be stocked with at least one seedling. They will also produce a substantial number of spots with two or three seedlings, and some spots with up to five seedlings. Reducing the sowing rate to three seeds per spot, even on 1,000 spots per acre, may create some risk of understocking. However, based upon these results of better growth from single trees, and direct seeding success from the use of good seeds, the recommended sowing rate probably should be changed. In an attempt to compromise between an adequate number of stocked spots and a reduction in multiple-spot stocking, the following recommendations are made: use seeds with a germinative capacity of 80 percent or more, sow five seeds per spot on 600 to 750 spots per acre four seeds on 750 to 900 spots per acre, or three seeds on more than 900 spots per acre. Sowing fewer spots with additional seeds decreases the labor involved, makes little difference in total seed requirements, but increases the chances for multiple-stocked spots. Manual thinning of multiple-stocked spots at age 2 or 3 years would be beneficial, but the economics of thinning must be decided by the land manager.

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HEIGHT GROWTH OF CONTAINERIZED WHITE PINE

ON THE CLJMBERLAND PLATEAU, TENNESSEE[1/]

Ronald L. Hay and John C. Rennie[2/]

Abstract .--Containerized white pine seedlings grown with various photoperiod and carbon dioxide treatments were outplanted on the Cumberland Plateau. Southeast and northerly aspects were mechanically site prepared before outplanting. Survival of all containerized seedlings was better than 2-0 bareroot seedlings after the first year, but the 24-hour photoperiod/enriched CO2 seedlings joined the 2-0 seedlings with poor survival after the second year. Seedlings grown with the continuous light in the greenhouse were taller after the second year but those grown with CO2 supplements in the greenhouse had significantly less height after two growing seasons. The better containerized seedlings were growing in height at a more rapid rate than 2-0 seedlings after the second year, although the latter remained significantly taller.

INTRODUCTION

Containerization of forest tree seedlings in the South has gained importance and acceptance recently. Southern tree species and containerized culture techniques were discussed at a recent symposium (Guldin and Barnett 1982). Major commitments to containerized culture of both pine and hardwoods have been made by some states, for example, North Carolina (Goodwin et al. 1982). Guldin (1982) has compared production costs between various containerized systems and bareroot nursery stock.

Containerized seedlings have been outplanted in forestry operations on a variety of sites. Some managers use them as a regular part of their regeneration program (Hahn and Hutchison 1978), while others emphasize containerized seedlings on problem sites such as strip mine reclamation sites (Hay and Woods 1980), borrow pit soils (Ruehle 1980), and extremely wet soils (Abbott 1982). Containerized seedlings have become an integral part of forest regeneration practices in North America.

Containerized culture of white pine (*Pinus strobus* L.) seedlings in East Tennessee was justified by the need for production of predictable quantities of viable seedlings that frequently was unattainable from bareroot nurseries due to production problems associated with this species in a warm climate. The demand for quality white pine seedlings in Tennessee has frequently exceeded the supply. Much of our preliminary work involved greenhouse culture treatments designed to stimulate seedling growth preparation for outplanting. Various container sizes, media formulations, fertilizer regimes, light and carbon dioxide (CO_2) supplements, and length of greenhouse culture were tried (Hay 1981). Some of the seedlings were outplanted on the Cumberland Plateau following clearcutting and mechanical site preparation on Pickett State Forest, Pickett County, Tennessee (Hay and Keegan 1982). It is our purpose to report seedling survival and height growth relationship for the first two growing seasons.

CONTAINERIZED SEEDLING PERFORMANCE

Survival

Cultural treatments and survival of seedlings that were outplanted on Pickett State Forest in 1980 were as follows:

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ The authors are Associate Professors, Department of Forestry, Wildlife, and Fisheries, The University of Tennessee, P. 0. Box 1071, Knoxville, TN 37901-1071.

Cultural Treatment	Survival Year 1	Year 2
2-0 bareroot nursery seedling5	79.2 b[1/]	77.3 b
?-month containerized seedlings		
1. natural photoperiod ambient CO2	89.2 a	85.3 ab
2. natural photoperiod enriched CO_2	88.0 ab	86.3 ab
3. 24-hour photoperiod ambient CO2	83.6 ab	80.7 ab
4. 24-hour photoperiod enriched CO_2	82.0 ab	77.3 b

1/ Mean groupings were at the 0.05 probability level as determined by Duncan's multiple range test.

The 2-0 bareroot seedlings were outplanted in March as dormant stock; the containerized seedlings were outplanted in May after frost damage was unlikely. The 2-0 seedlings had the poorest survival of all treatments, perhaps unacceptable low for stand establishment; most of the mortality occurred during the first year. The shock of outplanting, combined with a severe 1980 drought, significantly (a = .05) reduced survival. By the beginning of the second growing season most surviving bareroot stock was well-established, for there was only a slight reduction in numbers that year. However, these seedlings still had the poorest survival of all the treatments.

All containerized seedlings survived the first year equally well (α = .05). Seedlings grown under natural photoperiod tended to survive better than seedlings grown under continuous light. This trend continued through the second year as well. Perhaps the extensive drought of 1980 impacted survival of the 24-hour photoperiod seedlings more than it did the natural photoperiod seedlings. During the second year, enough of the 24-hour photoperiod/enriched CO_2 seedlings had died to rank with the 2-0 bareroot seedlings. The natural photoperiod seedlings continued to have the highest survival, although the position of the CO2 treatments was reversed. After two growing seasons most of the containerized treatments had established successful plantations.

In 1982, two additional plantations were established using 7 and 10 month old containerized seedlings. Mortality in these plantations caused concern. In the Pickett State Forest plantation, reasonable care was taken during planting to maintain the integrity of the root/media plug; except for considerable damage randomly inflicted by rabbits, mortality due to outplanting shock or greenhouse treatments appeared to be negligible through the middle of the growing season (final data have not been collected). In the Highland Rim plantation (Franklin County, Tennessee), the seedlings were planted by personnel other than our own. In spite of repeated instruction on techniques and the need to use great care, the rooting medium was frequently separated from the roots as the seedlings were wrecklessly dropped into the dibble hole. Mortality was high and it seemed correlated more with who planted the seedlings rather than greenhouse cultural treatments. White pine root/media plugs at 7 or 10 months of age were not sufficient to withstand rigorous handling during outplanting.

Deer Browse Damage

The deer herd on Pickett State Forest has been sufficiently large to periodically impact stand regeneration. The 1980 plantations experienced some deer browse damage during each of the first two growing seasons. Because site preparation had been effective in minimizing impact from competing vegetation (Keegan 1981), most white pine seedlings were exposed enough to be available for potential deer browse.

The 1980 outplantings were made on two sites in proximity to each other. Site 1, a southeasterly slope, had been sheared before planting. Deer browse was not a problem on Site 1, in spite of the nearly complete exposure of the seedlings due to lack of competing vegetation. Site 2, a northern aspect, had been prepared by removing logging slash with a dozer, but the soil was not scarified appreciably. Stumps were still in place, and hardwood sprouts were common. Deer browse damage to the white pine seedlings on Site 2 was quite heavy, significantly (a=.05) more so than on Site 1.

During the third growing season, deer browse damage to the seedlings had not been renewed through August. The amount of competing vegetation in the stands had increased appreciably providing considerable angiosperm browse and making the pine seedlings less conspicuous.

In spite of the frequent deer browse on Site 2, there was no preference for an individual cultural treatment (a = .05). All seedlings were apparently acceptable food, and the browse damage occurrence was a random selection by the animals. For purposes of height growth comparisons seedlings that had been browse damaged were not considered.

Seedling Growth Relationships

Height Growth

Analysis of variance on the first year

heights showed the 2-0 bareroot seedlings to be significantly taller ($a = .05$) than any of the other treatments; this was not unexpected considering their initial size. There were no significant differences among first year heights of greenhouse culture treatments; Duncan's multiple range test ranked the natural photoperiod/ambient CO2 treatment in the same group as the 24-hour photoperiod/enriched CO2 treatment. Based on this information, the additional expenses of electricity for the lights and propane for the CO2 generator did not produce additional growth benefits.

After the second growing season, the 2-0 bareroot seedlings remained significantly ($a = .01$) taller than all the containerized seedlings. This *trend* will undoubtedly continue for several years, but the better containerized treatments grew proportionally faster than the 2-0 seedlings, thereby reducing the total difference in height. At some point in time, the containerized seedlings and 2-0 bareroot seedlings will likely approach the same total height, probably before the period of rapid height growth ceases and perhaps as early as the large sapling stage.

Photoperiod effects.--During the second growing season the effects of 24-hour photoperiod and enriched CO_2 atmospheres in the greenhouse culture phase had significant ($a = .05$) impacts on seedling height growth. Those seedlings that had been grown with 24-hour photoperiod *were* significantly taller than those grown with natural photoperiod while the enriched CO2 atmosphere depressed height growth.

	Natural Photoperiod cm	24-Hour Photoperiod cm	Mean cm
ambient CO_2	21.8	22.8	22.3 1/
enriched CO_2	18.9	21.8	20.4
mean	20.4 1/	22.3	

1/ Means were significantly different at the .05 probability level.

After the first growing season in the field, there were no significant differences in seedling height among the containerized seedlings. It was apparent, however, that the 24-hour photoperiod in the presence of supplemental CO2 benefited seedling height compared to natural photoperiod in the same CO_2 atmosphere. This trend continued through year two. The growth benefits of continuous light were sufficient to balance the growth depression of supplemental CO_2. Maximum increased growth was evident in the 24-hour photoperiod/ambient CO2 treatment.

In the greenhouse culture phase of this work, there was no impact on height growth through age seven months due to different photoperiod treatments (Hay and Keegan 1982). However, there was a significant increase in biomass of both tops and roots due to the 24-hour photoperiod treatments. The impact of the increased biomass during greenhouse culture upon seedling growth in the field may have been delayed until the second year. The first year had a prolonged, severe drought during most of the summer and seedling establishment was difficult. Weather during the second year was more average and seedling growth may have been a more realistic reflection of greenhouse culture treatments. Subsequent measurements will have to be made to confirm these trends, plus additional outplantings will be established to provide more information.

CO_2 effects.--Seedlings that had been grown in a CO_2 enriched atmosphere during greenhouse culture-were significantly ($a = .05$) shorter than seedlings grown in ambient CO_2 concentrations, both at seven months (Hay 1981) and after *two* years in the field. The same trend was apparent after the first year in the field but the heights were not significantly different. Seedling height growth in the CO_2 enriched treatment increased slightly when the photoperiod was increased to 24 hours. However, seedling height attained after two years in the field for the expensive continuous light and CO2 enrichment treatments was the *same* height attained by seedlings grown in ambient CO2 concentration with just enough light interruptions of the dark phase to prevent bud-set and dormancy.

These results do not seem consistent with the role of the CO_2 in photosynthesis and carbohydrate accumulation, and the increased growth potential made possible through both processes. However, the effects of CO_2 as used during the greenhouse culture phase have been consistent throughout the period of this experiment. At no time did the seedlings show the symptoms of CO2 toxicity, but it was possible that excessive CO_2 or impurities in the propane could have had harmful effects on the seedlings. The foliage maintained healthy, blue-green color and had good secondary leaf development. In fact, the seedlings with the best appearance at 7 months of age were the 24-hour photoperiod/enriched CO_2 treatment seedlings. Those grown without continuous light were not very robust in appearance.

There has been no evidence, based on this work, to warrant the use and expense of a CO2 generator, at least according to the conditions available to us. Enriching the atmosphere with CO2 had a negative impact on growth through the second growing season in the field.

Site effects.--White pine prefers cool, moist sites and it is most common in drainages or along northern aspects on the Cumberland Plateau. It has been planted successfully in the past, however, on a variety of sites. Some of the older plantations on Pickett State Forest have recently been thinned for small sawlogs. The residual trees are impressive.

Our seedlings were outplanted on two sites at Pickett State Forest. Site 1 was a 20 percent slope, southeast aspect that had been sheared, removing stumps, slash, and some soil, including most of the unincorporated organic matter. Site 2 was a 30 percent slope on a northern aspect. Logging slash had been pushed from the site by a dozer, but there was no attempt to remove stumps and the soil was not appreciably scarified. Soil analyses showed that the mineral soil on both sites contained similar levels of the important nutrients.

The amount of competing vegetation that occurred on both sites through July of the second growing season did not impact white pine seedling growth (Keegan 1981). However, competing vegetation was more abundant on Site 2, principally sprouts and vines. Herbaceous species were well represented on both sites comprising most of the competing vegetation on Site 1 through the second growing season.

Sprouts on Site 2 constituted a vigorous stand by late summer of the third growing season. Although sampling was not done according to the design used previously (Keegan 1981), it was apparent that the white pine seedlings were experiencing considerable crowding from the sprouts. Herbaceous vegetation on Site 2 was less prominent than during the first two years being outgrown by sprouts and the pine seedlings. Some of the hardwood sprouts have the potentfal to grow into the overstory with the white pine but most of them will either be understory shrubs or small trees at maturity. Their effect will become insignificant when the pine canopy closes.

On Site 1, sprouts remained infrequent into the third growing season and herbaceous plants continued to dominate. Numerous Virginia pine (*Pinus virginiana* L) wildlings were interspersed throughout the plantation and some of them may compete with the white pine for a period after the canopy closes.

In response to its preference for a northern aspect, white pine grew better on Site 2, at least in part because site preparation retafned most of the unincorporated organic matter on the site. These soils have always been marginally productive and there has been a long history of abuse through wildfire and high-grading. Enhancing soil fertility and moisture availability by maintaining the organic matter benefited seedling growth. It was unfortunate that the southerly aspect (Site 1) was sheared to the mineral soil because the undesirable effects of low soil fertility and low available soil water were compounded.

Height Growth Patterns

When these seedlings were taken from the greenhouse to the field at age seven months, many of them had secondary leaves and their terminal buds were actively elongating. During the first growing season some seedlings produced considerable height growth and the new tissue supported primary leaves. This burst of stem elongation was not further growth of the same tissue that was being produced in the greenhouse, rather juvenile characteristics dominated (fig. 1). Initially the sudden change from 24-hour photoperiod

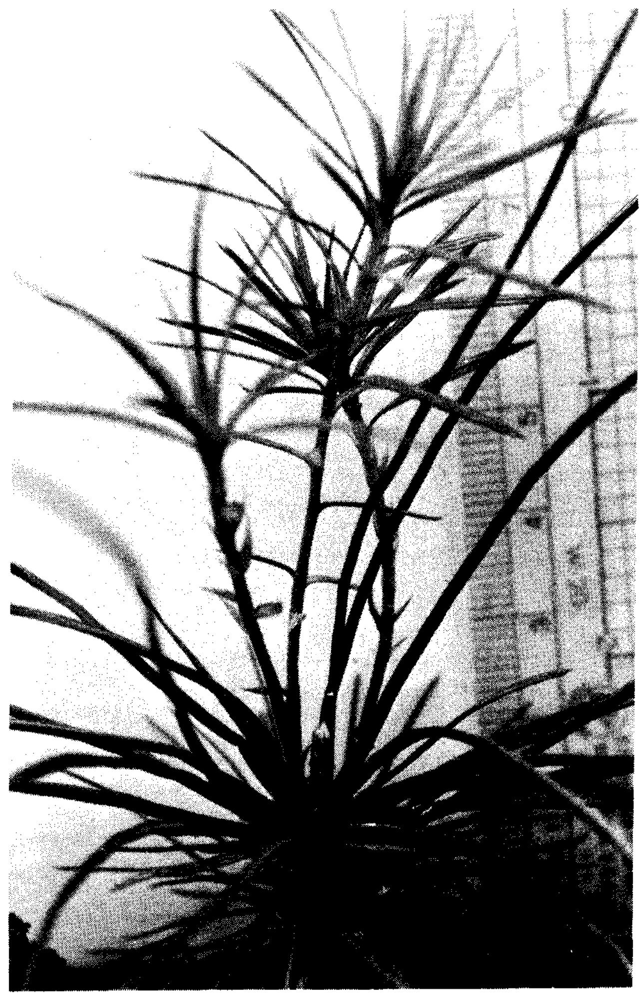

Figure 1.--White pine seedling growth form with buds at the leaf axils providing the new tissue while the terminal bud remained dormant. Note the primary leaves, indicative of juvenile characteristics.

to natural photoperiod when the seedlings were moved to lath shade was thought to have caused partial dormancy of terminal buds, followed by a reversal to juvenile tissue production when growth resumed. Careful examination revealed that it was not the terminal bud that had produced the burst of height growth. A secondary bud that formed at one of the secondary leaf axils produced the stem tissue complete with primary leaves. Occasionally, multiple leaders were produced, individually in each of several leaf axils without any particular one gaining dominance. The terminal bud on the main stem was always present and dormant.

The original terminal bud was usually well-formed and appeared to be ready for growth in 1983. It was not apparent at the time the seedling in figure 1 was photographed whether the terminal bud had elongated normally during the growing season or whether it had gone dormant soon after outplanting.

It is not yet possible to correlate this growth form to any particular greenhouse treatment or age of the containerized seedling at outplanting. The 1982 seedlings were either 10 or 8 months of age having been seeded in August or October, 1981. They were outplanted in May while actively growing without ever having been dormant. Seedlings in an unrelated test were allowed to over-winter outside before being outplanted as dormant stock in April, 1982. These seedlings were approximately 12 months of age at outplanting and the terminal bud maintained strong dominance during the 1982 growing season.

DISCUSSION

Some Silvicultural Considerations

Seedling Growth

Although the containerized seedlings were initially quite small compared to the 2-0 bareroot nursery stock, they have shown good performance since outplanting on the Cumberland Plateau. One greenhouse culture treatment survived significantly better than the 2-0 bareroot seedlings. Much care was exercised in planting all these trees, at least in part due to their experimental purposes. Perhaps the containerized seedlings would not have survived so well if these seedlings had been assigned to commercial planting crews. Destruction of the root/media plug on a containerized seedling would significantly increase mortality.

The height growth rate of the 2-0 bareroot seedlings was less than the height growth rate of the containerized seedlings. The 2-0 seedlings increased in height 117 percent during the second year while the best containerized treatment seedlings increased in height by 165 percent. Although the 2-G seedlings were still significantly taller, the differences were decreasing' yearly because the containerized seedlings were growing more rapidly. Soon the heights will become equal; certainly the mature stand will show no differences.

Site Preparation

Site preparation in these small clearcuts was adequate. However, shearing was not necessary and it was actually harmful because so much of the organic matter was removed from Site 1. Slash removal on Site 2 was helpful for the planting operation but there was little benefit to the white pine seedlings since there was no attempt to minimize sprouting. Heavy disking may have been more appropriate for the seedlings because the mineral soil would have been scarified and some sprouting would have been discouraged. Also the organic matter would have been mixed with mineral soil. Site preparation that incorporated the best part of slash removal with mixing the organic matter and the mineral soil would be best for similar sites on the Cumberland Plateau.

Prescribed burning for site preparation was not a part of this experiment, but fire has certainly been no stranger to the Cumberland Plateau. Past wildfires have been one of the major sources of site and stem degradation. Plateau soils are shallow sands overlying bedrock and they are marginally productive. Where topography is so steep that surface flow during a rain storm would erode nutrients released by combustion, prescribed burning would not be good management. On suitable sites, prescribed burning followed by heavy disking would adequately prepare the site for outplanting while providing released nutrients for good seedling growth.

The Root/Media Plug

One of our greatest concerns in this work has been identifying the combination of container size, rooting medium, and greenhouse culture techniques that will provide seedlings capable of surviving outplanting and growing rapidly on a variety of sites. Although we have reported on survival and height growth here, there is still much to be accomplished in developing a root/media plug strong enough to withstand handling by more careless workers.

The seedlings used in this experiment were grown in a peat-sand-pine bark mix and root development was not sufficient to hold the plug together (Day and Keegan 1982). If extreme care had not been used in outplanting, survival would have been quite low. The seedlings were not satisfactory for commercial use.

In subsequent greenhouse work various other media have been used, ranging from peat-vermiculite (50-50) to pine bark-vermiculite (85-15).

At 8 and 10 months of age, white pine roots had not adequately secured the root/media plug to withstand careless handling, but the peat-vermiculite mix was best. Future work has been planned to help solve this problem and the most promising idea may well be to lengthen the time in greenhouse culture, taking 12 to 15 month old stock to the field.

Seedlings started in the greenhouse during early January would have growing time equivalent to two seasons in the nursery by September, especially if extended photoperiods were used. These seedlings could then be outplanted if the root/media plug was acceptable and if frost heaving would not be a problem. Another alternative would be to place them in a shade house, seated in woodshavings and sawdust, for the winter. They could be outplanted as dormant stock during late winter or after growth was initiated in the spring, thereby increasing operational flexibility.

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FIRST YEAR SURVIVAL AND GROWTH OF CONTAINERIZED PINE (PINUS SPP.) SEEDLINGS ON STRIP MINED LANDS AS AFFECTED BY CULTURAL TREATMENTS AND EDAPHIC FACTORS[1/]

Stephen H. Schoenholtz and James A. Burger[2/]

Abstract.--The effects of cultural treatments including ectomycorrhizal inoculation, chemical weed control, and slow-release fertilization on first year survival and growth of of containerized P. strobus, P. virginiana, and P. taeda seedlings planted on a return-to-contour and a flat bench strip mine site in southwestern Virginia were studied. First year survival was not significantly affected by the cultural treatments or site factors; however, mycorrhizal inoculation, fertilization, and weed control improved growth of all three species. A combination of fertilizer and chemical weed control had an additive effect. These three cultural treatments could be used to improve seedling growth on reclaimed strip mine sites.

INTRODUCTION

Much of the coal producing region of southwestern Virginia has been or will be strip mined for bituminous coal. Once the coal has been extracted from these areas, they are often left in an unproductive state. There is a challange to return these disturbed coal spoils into productive land for agriculture, wildlife, water management, and recreation. On many of these disturbed sites, reforestation is a justifiable alternative for reclamation.

In the past fifty years most research has focused on species' adaptability for revegetation and stabilization of strip mines. In general, pines (Pinus spp.) have proven to be suitable because of their ability to survive and grow in harsh soil environments.

Much of the progress in developing cultural practices for tree establishment has been more recent. Some of the first observations and studies of ectomycorrhizae on surface mine spoils were reported by Schramm (1966). He concluded that early ectomycorrhizal development with Pisolithus tinctorius (Pers.). Coker and Couch (P.t.) was vital for seedling establishment of several tree species on spoils in Pennsylvania. Since Schramm's work, numerous other reports supporting these original findings have been published (Berry 1982; Ruehle 1980; Walker, et al. 1980; Marx and Artman 1979; Berry and Marx 1978; Marx and Barnett 1974; Marx and Bryan 1971; and Marx et al. 1970).

The primary concern for revegetating strip mined lands is to control erosion. Herbaceous plants have been used successfully to accomplish this goal. Trees grow too slowly and have low stocking densities which do not provide adequate cover for erosion control. Mays and Bengston (1978) suggested that tree species could be planted several months after an herbaceous ground cover was established to control erosion. Herbaceous vegetation, however, tends to compete with desirable tree seedlings for soil water, soil nutrients, and light (Klingsman and Ashton 1975). Herbaceous plants also have been shown to have an allelopathic effect on tree seedlings.

When herbaceous vegetation competes significantly with tree seedlings, the competing vegetation can be controlled to release limited site resources. There have been numerous reports describing significant responses in pine growth to chemical weed control during the first few years of plantation

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establishment (Haines 1978; Nelson et al. 1981a, 1981b). However, very limited information is available on the effects of weed control on surface mine reforestation in the South. In addition, the interactions between herbicides and ectomycorrhizae have received limited study (Smith and Ferry 1979; and Kelley and South, 1980).

The effectiveness of fertilizer applications in promoting survival and growth of tree species depends, in part, on the extent of herbaceous competition on the site. Weed competition can be greatly stimulated by applications of soluble fertilizers and overfertilization may result in overtopping of tree seedlings by excessive development of herbaceous cover (Mays and Bengtson 1978).

Mays and Bengtson (1978) indicated that strip mine spoils may be highly porous, low in cation exchange capacity, and often lacking much of the fertilizer retention capacity of normal soils. Conventional fertilizer sources may leach rapidly through these disturbed soils. Slow-release fertilizer tablets, however, offer a potential solution to this problem. Tablets placed adjacent to seedling roots provide maximum benefit for the seedling while minimizing the effect on competing weeds.

The purpose of this study was to evaluate the effects of ectomycorrhizal inoculation, chemical weed control, and slow-release fertilization on first year survival and growth of white (P. strobus L.), Virginia (P. virginiana Mill.) and loblolly (P. taeda L.) pines on two strip mined sites in southwestern Virginia.

MATERIALS AND METHODS

Study Sites

The two study sites are located in Wise County, Virginia. Most surface mined sites in this mountainous region of southwestern Virginia were left as flat benches after contour mining operations terminated. Federal regulations now require operators to return mining sites to their approximate original contour, which results in sites of relatively steep slope. First year seedling survival and growth were evaluated on both types of site.

On the flat bench site, three replicate blocks, each with six 57 x 66 ft (17.5 x 20.0 m) plots, were established on two adjacent areas of similar reclamation histories and site conditions. The bench site was mined in 1977 and 1978 and hydroseeded with a combination of Kentucky-31 fescue (Festuca arundinacea Schreb.), red clover (Trifolium pratense L.), ladino clover (Trifolium repens ladino L.), annual rye (Lolium multiflorum Lam.), and red top (Agrostis alba L.) in mixture with 365 lb/acre (409 kg/ha) of 16-27-14 fertilizer and 833 gal/acre (9354 liters/ha) of Conweb® mulch.

The return-to-contour site was mined in 1979. It was hydroseeded with a combination of Kentucky-31 fescue, red top, ladino clover, annual rye, and annual lespedeza (Lespedeza cuneata (Dumont) G. Don) in mixture with 500 lb/acre (560 kg/ha) of 10-20-20 fertilizer and 1500 lb/acre (1681 kg/ha) of wood fiber mulch. Three replicate blocks, each with six 57 x 66 ft (17.5 x 20.0 m) plots were established on this site.

A composite soil sample made up of 15 subsamples was taken from each plot for soil characterization of the sites. Percent slope and standing herbaceous biomass were estimated for each plot.

Plot Design and Treatments

The three pine species (white, Virginia, and loblolly) and two fertilizer treatments (21 gm slow-release Agriform® fertilizer tablets and control) were evaluated in factorial combination. Two mycorrhizal treatments (P.t.-inoculated seedlings and control seedlings) and two weed control treatments (glyphosate applications and control) were imposed on these combinations as split plots.

Plots were planted with 136 trees using a 4 x 8 ft (1.25 x 2.50 m) spacing. Each plot was divided into four subplots to accommodate the mycorrhizal and herbicide treatments.

In January, 1981, white, Virginia, and loblolly pine seeds were planted in Spencer-Lemaire Hillson® root trainers containing a 1:1 v/v peat-vermiculite mixture. One half of the seedlings were inoculated with P.t. mycelia, which had been cultured following techniques of Marx and Bryan (1975). Prior to outplanting in June, 1981, 30 control seedlings and 30 inoculated seedlings of each species were destructively sampled and inspected for the presence of P.t. or other mycorrhizal fungi.

A 21 gm Agriform® starter tablet was placed in the soil within 4-6 in (10-15 cm) of each seedling in 18 of the 36 plots at the time of planting. The tablets are formulated to release nutrients for two growing seasons.

Glyphosate at a rate of 0.5 qt/acre (1.5 l/ha) was applied to a randomly selected half of each plot two weeks prior to planting and again in August to control competing vegetation. Seedlings were protected by paper bags during the second herbicide application.

Data Collection

In November, 1981, survival, height, and root collar diameter were measured. Needle samples from each tree were collected and composited by treatment combination. The needle samples were analyzed for P, K, Ca, and Mg. In addition, twelve seedlings in each plot (three from each subplot) were destructively sampled to determine the presence of ectomycorrhizae.

Soil moisture was measured gravimetrically at intervals from July through November. Weekly precipitation at both study sites was compiled from June through November.

RESULTS

Of the inoculated seedlings, 4 percent of white, 23 percent of Virginia, and 26 percent of loblolly pine seedlings were colonized by P.t. prior to outplanting. No other ectomycorrhizal fungi were detected on the inoculated seedlings, and no ectomycorrhizae of any type were observed on the control seedlings.

The site characterization data show three main differences between the return-to-contour and the flat bench sites (Table 1). The **return-to-contour** site had greater slope, a soil texture dominated by silt and clay, and consistently higher levels of soil nutrients.

Table 1.--Soil and site characterization of the return-to-contour and flat bench sites used in the study.[1/]

	Site	
Site Parameter	Return-to-Contour	Flat Bench
Slope (%)	38	<2
Biomass (tons/acre)	1.70	1.73
Particle Size Distribution (%)		
Coarse Fragments	49	43
Sand	12	29
Silt	21	16
Clay	18	12
Bulk Density (g/cc)	1.3	1.4
Organic Matter (%)	1.2	1.8
pH	5.4	6.1
P (ppm)[2/]	7.6	6.3
K (ppm)[3/]	100.7	61.7
Ca (ppm)	610.2	576.0
Mg (ppm)	431.0	255.1

1/ Values are the means of measurements from 18 plots at each site.

2/ Sodium bicarbonate extract.

3/ Cation levels are for ammonium acetate extracts.

First-year survival and growth of all three pine species were not significantly different between the two sites (Table 2). Survival and growth of white and Virginia pines were not significantly affected by mycorrhizal inoculation, whereas inoculation with P.t. did significantly increase the average volume of loblolly pine. Inoculated loblolly seedlings averaged 20 percent more volume than control seedlings. Although insignificant, the favorable effect of inoculation is also shown by increased volume means for white pine and Virginia pine. Inoculation of these two species increased seedling volume by 15 and 19 percent, respectively.

There was a synergistic fertilizer x herbicide interaction which significantly affected the growth of all three pine species but did not significantly influence their survival (Table 3). Fertilizer alone increased the average white, Virginia, and loblolly pine seedling volumes by 10, 73, and 99 percent, respectively, over herbicide alone. However, the combination of fertilization and herbicide significantly exceeded these average volumes. White pine volume was increased by 62 and 79 percent, Virginia pine by 149 and 330, and loblolly pine by 109 and 317 percent over fertilization and herbicide alone, respectively.

The herbicide treatment significantly increased soil moisture 'levels on the contoured site on four of six sampling dates, July 17, July 24, August 5, and August 21 (fig. 1). By contrast, the soil moisture contents were significantly different at only one of the measured times on the bench site, September 27 (fig. 2).

The percentage of white and loblolly pine seedlings colonized by P.t. was higher on the flat bench site, while the reverse was true for Virginia pine (Table 4). The number of seedlings colonized by other fungi was significantly higher on the flat bench site which resulted in significantly higher total colonization for each species on the bench site.

Inoculation significantly increased the percentage of Virginia and loblolly pines colonized with P.t. P.t. was also present on some uninoculated seedlings of all three species. Although a substantial amount of natural colonization occurred, the total number of trees colonized with either P.t. or other ectomycorrhizal fungi was significantly higher for inoculated trees.

Chemical weed control tended to enhance natural colonization resulting in significantly higher total colonization of all three pine species (Table 4). In contrast, the percentage of Virginia and loblolly seedlings colonized with P.t. or with other ectomycorrhizal species was somewhat inhibited by fertilization. Fertilized white pines exhibited an opposite trend (Table 4).

Foliar P and K levels in Virginia, and P levels in loblolly pine, were significantly higher on the flat bench site (Table 5). Foliar Ca and Mg levels tended to be higher on the return-to-contour site; however, the increase was significant only for Mg levels in loblolly pine. One exception to this trend was the significantly higher level of white pine foliar Ca on the flat bench site.

Table 2.--Effects of mining site and mycorrhizal treatment on first-year survival and growth of pine seedlings.[1/]

Site and Mycorrhizal Treatments	White pine Survival	White pine Volume[2/]	Virginia pine Survival	Virginia pine Volume	Loblolly pine Survival	Loblolly pine Volume
	(%)	(cm^3)	(%)	(cm^3)	(%)	(cm^3)
Mining Site						
Return-to-contour	94a	0.33a	97a	1.18a	98a	1.81a
Flat bench	92a	0.38a	99a	1.13a	97a	2.60a
Mycorrhizal Inoculation						
Control	91a	0.33a	98a	1.05a	97a	2.00a
Inoculated	94a	0.38a	97a	1.25a	98a	2.41b

1/ For each treatment and species, means within columns not followed by the same letter are significantly different at the 0.05 level.

2/ Volume = ht x $diam^2$

Inoculated loblolly pine seedlings had significantly higher foliar P levels than uninoculated seedlings, and inoculated white pine seedlings had significantly increased levels of K. Other foliar nutrient levels for the three species were not significantly affected by the ectomycorrhizal treatment. Concentrations for all of the nutrients analyzed were above deficiency thresholds for both uninoculated and inoculated seedlings.

The herbicide treatment did not significantly affect foliar nutrient levels, whereas fertilized seedlings had significantly lower levels of Ca and Mg than unfertilized seedlings. Nutrient concentrations were above deficiency thresholds for both treatments and controls.

DISCUSSION

None of the cultural treatments on the two sites significantly affected pine seedling survival. In fact, first year seedling survival for all three treatments on both sites was excellent (Tables 2 and 3). This was probably due to ample and well distributed rainfall during the growing season (figs. 1 and 2).

The benefit of P.t. inoculation is evident even though colonization with other native ectomycorrhizal fungi occurred. Loblolly pines, which showed the most substantial increase in seedling volume when inoculated, had the highest percentage of seedlings colonized with P.t. Berry (1982), Ruehle (1980), Walker et al. (1980), and Marx and Artman (1979) have reported similar growth improvement of P.t. inoculated seedlings on

Table 3.--Effects of fertilizer x herbicide interactions on seedling survival and growth.[1/]

Fertilizer Treatment	Weed Control Treatment	White pine Survival	White pine Volume[2/]	Virginia pine Survival	Virginia pine Volume	Loblolly pine Survival	Loblolly pine Volume
		(%)	(cm^3)	(%)	(cm^3)	(%)	(cm^3)
Control	Control	93a	0.29a	97a	0.46a	96a	0.74a
Control	Herbicide	95a	0.29a	99a	0.59a	96a	1.13a
Fertilized	Control	93a	0.32a	98a	1.02b	98a	2.25b
Fertilized	Herbicide	91a	0.52b	97a	2.54c	99a	4.71c

1/ Means within columns not followed by the same letter are significantly different at the 0.05 level.

2/ Volume = ht x $diam^2$

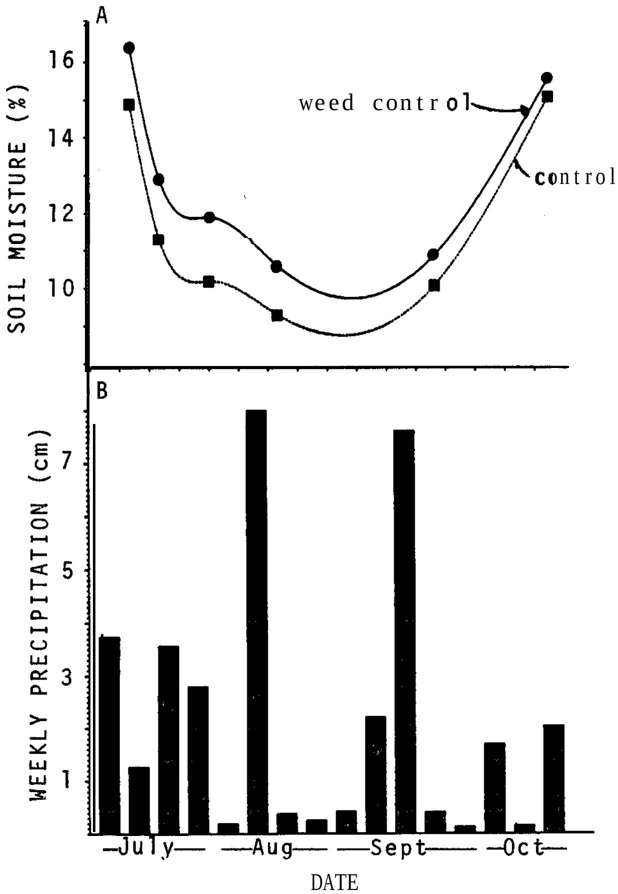

Figure 1.--Soil moisture and weekly precipitation on the return-to-contour site.

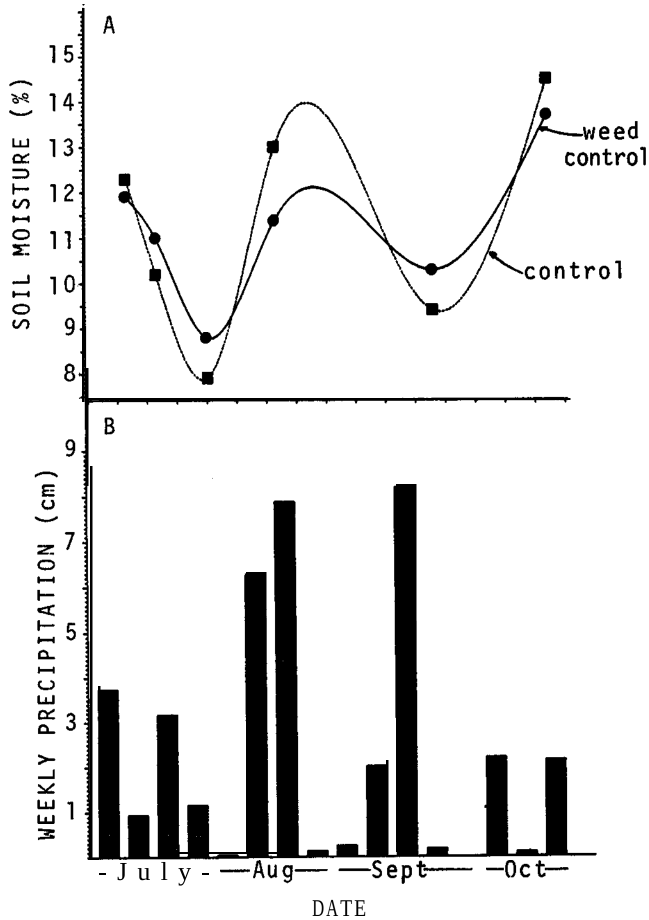

Figure 2.--Soil moisture and weekly precipitation on the flat bench site.

disturbed sites in the South. The relationship between P.t. colonization and increased seedling growth is apparent for all three species (Table 2).

Chemical weed control did not significantly increase seedling growth except when it was used in combination with fertilization. This may be attributed to the regular and abundant precipitation which occurred throughout the growing season on both sites. The amount of available moisture is usually the most important consideration in evaluating the effects of vegetative competition. Greaves et al. (1978) reported that heavy stands of grass may deplete moisture to the point where conifer seedlings must survive for several months each year with minimum available moisture.

Seedling growth of all three pine species was enhanced by fertilization. This agrees with the results of studies by Berry (1979) and Marx and **Artman** (1979) which showed the beneficial effects of slow-release fertilizer tablets on early loblolly pine growth on disturbed sites. When fertilizer and chemical weed control were combined, the most substantial growth stimulation occurred. The slow-release fertilizer tablets appear to be effective in providing seedlings with adequate nutrients and at the same time not stimulating unwanted herbaceous competition during the initial year of pine seedling establishment.

The ectomycorrhizal colonization data indicated that the relatively high natural colonization of seedlingson the bench site may help account for the lack of survival and growth differences in comparison to the contour site which had more favorable soil nutrient levels. The percentage of uninoculated and inoculated seedlings colonized with P.t. increased by the end of the first growing season indicating that P.t. is probably one of the native fungi on these two sites. Other ectomycorrhisal fungi were not evident when seedling root systems were examined prior to outplanting.

Chemical weed control did not affect the number of trees colonized with P.t. However, it did stimulate sufficient colonization by other fungi to result in a significant increase in total

Table 4.--Effects of mining sites and cultural treatments on the percentage of trees colonized with mycorrhizal fungi[1/]

Site and Cultural Treatments	Species	Trees Colonized	Trees Colonized with P.t.	Trees Colonized With Other Species
		%		
Mining Site				
Return-to-contour	White pine	14a	1a	12a
Flat bench		58b	10b	49b
Return-to-contour	Virginia pine	56a	22a	36a
Flat bench		79b	17b	69b
Return-to-contour	Loblolly pine	60a	18a	42a
Flat bench		86b	25a	68a
Mycorrhizal Inoculation				
Control	White pine	30a	1a	29a
Inoculated		42b	10a	32a
Control	Virginia pine	60a	8a	58a
Inoculated		75b	31b	47b
Control	Loblolly pine	67a	6a	62a
Inoculated		79b	38b	47a
Weed Control				
Control	White pine	28a	7a	21a
Herbicide		44b	4a	40b
Control	Virginia pine	57a	22a	36a
Herbicide		78b	17a	69b
Control	Loblolly pine	69a	21a	54a
Herbicide		76b	22a	56a
Fertilizer				
Control	White pine	33a	4a	29a
Fertilized		39b	7a	32a
Control	Virginia pine	71a	22a	56a
Fertilized		64a	17a	50a
Control	Loblolly pine	75a	24a	56a
Fertilized		71a	19a	54a

1/ For each treatment and species, means within columns not followed by the same letter are significantly different at the 0.05 level.

Table 5.--Effects of mining site on pine needle nutrient levels[1/]

Species and Mining Site	P	K	Ca	Mg
	%			
White pine				
Return-to-contour	0.16a	0.36a	0.47a	0.29a
Flat bench	0.16a	0.34a	0.53b	0.28a
Virginia pine				
Return-to-contour	0.11a	0.42a	0.37a	0.24a
Flat bench	0.16b	0.52b	0.35a	0.21a
Loblolly pine				
Return-to-contour	0.12a	0.50a	0.33a	0.20a
Flat bench	0.18b	0.51a	0.32a	0.17b

1/ For each species, means within columns not followed by the same letter are significantly different at the 0.05 level.

ectomycorrhizal colonization. Glyphosate may have stimulated the ectomycorrhizal fungi by changing the soil microbiological balance which resulted in more favorable conditions for colonization.

Fertilization did not have a significant inhibitory effect on ectomycorrhizal colonization for any of the pine species. Contrary to a study by Marx et al. (1977), P.t. did improve growth of seedlings on fertilized plots.

None of the cultural treatments had very striking effects on foliar nutrient levels. Nutrient levels for all three treatments were above deficiency threshold levels indicating that P, K, Ca, and Mg were not limiting to seedling growth, The stimulatory effect of fertilization suggests that N may be limiting.

CONCLUSIONS

Abundant precipitation throughout the initial growing season probably accounted for the excellent first-year survival for all treatments and all species. It may have also accounted for the insignificant effect of chemical weed control on first year seedling growth.

Seedling growth was enhanced by P.t. inoculation, fertilization, and the fertilizer x herbicide interaction. Thus, the three cultural treatments were compatible in providing increased first-year growth for all three pine species.

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CONTAINER-GROWN PINE SEEDLINGS ENABLE EXTENDED PLANTING SEASON

ON SURFACE MINES IN EAST TENNESSEE [1/]

Peter Moditz and Edward **Buckner** [2/]

Abstract.--Eight groups of containerized **loblolly** and Virginia pine seedlings were grown in a greenhouse using methods developed by the North Carolina Division of Forestry. This enabled outplanting on surface mine sites at 3-4 week intervals from May through September. Survival after the first summer was over 90% for all planting dates. This indicates that containerized seedlings can be used to lengthen the short planting season typical on surface mines. Because of high overall survival, treatments intended to improve survival (mycorrhizal inoculation and disking) had no significant effects.

INTRODUCTION

Poor growing conditions for tree seedlings are characteristic of surface mines even when they have been reclaimed to conditions that meet reclamation requirements. Unfavorable conditions for seedling survival and growth include low **pH,** acid-induced toxicities, nutrient deficiencies, stoniness and poor soil structure.

Frozen ground and seedling losses to frost heaving generally restrict the planting season on surface mines in East Tennessee to the short period from ground thaw in late winter to May 1. Wet, muddy conditions during this period often make surface mines inaccessible or planting difficult, further reducing the length of the planting season especially at higher elevations. These limitations commonly result in failure to complete the tree planting program scheduled for a season.

Reclamation laws require the successful establishment of trees, therefore planting delays and high seedling mortality can delay bond release for several years. Although pines are preferred on reclaimed sites because their evergreen habit offers better year-around site protection and they yield salable products, high seedling mortality discourages their use. Many operators have resorted to planting almost exclusively black locust (Robinia pseudoacacia L.) because compared to pines it is easier to plant and has higher survival. Black locust is, however, a short-lived tree that has little commercial value and offers little protection to surface mine sites during winter months.

Efforts to extend the planting season into late spring and early summer (when surface mines are generally more accessible) have met with only limited success. Woods, Hay and Irwin (1978) demonstrated that modification of the planting microsite and the use of containerized pine seedlings enables successful tree planting as late as mid-June on surface mine sites in this region. The high cost of this operation makes this practice prohibitive.

Other studies have shown that containerized pine seedlings can be successfully planted **year-**around (Bamett and **McGilvray,** 1981). In North Carolina a State-sponsored research program on containerized pine seedlings has evolved into a production facility that provides landowners with containerized seedlings for year-around planting. However, these studies have not been on adverse sites such as surface mines. Guldin (1982) claims that small, fast grown (12-16 weeks) containerized pine seedlings of high quality can be produced at a cost comparable to that of bare-root seedlings from nurseries.

[1/] **Paper** presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

[2/] **Graduate** Research Assistant and Professor of Forestry, respectively, in the Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Knoxville, TN.

In a pilot study Buckner and Evans[3] planted containerized seedlings on surface mines in East Tennessee as late as the first week of July and achieved over 80% survival. They found that where the planting situation is difficult and suitable times for planting are unpredictable, containerized seedlings can be held without damage for several weeks until planting conditions are most favorable to survival.

In addition to harsh site conditions, seedling survival and growth on reclaimed surface mines is further reduced by the required establishment of grasses and legumes shortly after final grading. This herbaceous material competes with planted seedlings commonly causing high mortality and reduced growth (Vogel, 1980). Seedling vigor on surface mines is further reduced by the absence of mycorrhizae-forming fungi. This symbiotic relationshfp is especially important on poor sites. Seedlings from commercial nurseries are only weakly mycorrhizal due to fumigation and high fertilization. Furthermore, fungal species that may be present are generally not the ones best suited for poor sites. Marx (1980) has shown that Pisolfthus tinctorius, a mycorrhizae-forming fungus on pines, improves the survival and growth of seedlings planted on poor sites such as surface mines.

The objective of this study was to evaluate the use of small, fast-grown containerized pine seedlings for extending the planting season and improving survival on surface mines over that generally obtained using bare-root seedlings from a nursery. Mycorrhizal inoculation and disking to control herbaceous competition were included as test variables.

METHODS

Since containerized seedlings are not generally available for forest planting for this region, the initial phase of this study was the growing of containerized seedlings on a schedule that would produce 'hardened" seedlings ready for out-planting at two-week intervals. Loblolly pine (Pinus taeda L.) is more widely planted on surface mines due to its availability and fast growth on most sites, while Virginia pine (Pinus virginiana L.) is the native yellow pine most commonly found on poor sites in this region. Both species were included in this study.

Treatments tested for improving the survival and growth of containerized seedlings were: 1) inoculation of the rooting medium with spores and mycelia of Pisolithus tinctorius, and 2) disking to reduce herbaceous competition.

[3] Personal communication with E. Buckner and R. Evans of the University of Tennessee.

Containerized Seedling Production

Methods developed by the North Carolina Division of Forestry for growing containerized pine seedlings were generally followed in the greenhouse phase of this study. Containers were Spencer Lamaire "root-trainers" (also known as book planters) with cavity dimensions of 3/4" x 3/4" x 4" having a volume of 2.25 cubic inches. Terra-lite redi-earth, a commercially available peat-vermiculite mix was used as a rooting medium. It has physical and chemical properties similar to those recommended by the N.C. Division of Forestry.

Pisolithus tinctorius spores were collected from funnal fruiting bodies in a loblolly pine plantation on a surface mine on the Cumberland Plateau of East Tennessee. Mycorrhizal roots were obtained from these trees, chopped in a blender, and mixed with the spores in a water slurry. This mixture was thoroughly blended with the rooting medium used to germinate half of the seedlings of each species.

Loblolly and Virginia pine seeds from superior-tree orchards were stratified for 30 days prior to seeding. Seedlings were grown for outplantings at 3-4 week intervals from May 21, 1982 through September 26, 1982. Greenhouse germination of seeds for the first outplanting was started November 24, 1981; germination of seed lots for later plantings followed at 2-3 week intervals. Seedlings remained in the greenhouse for 11-16 weeks; the length of this initial growth period decreasing as the length of the day increased. While in the greenhouse, seedlings were fertilized weekly with a 20-20-20 fertilizer solution. Once they reached "plantable" size (6-8"), they were moved outside for hardening which required from 5 to 9 weeks. During hardening, the seedlings were fertilized only to offset apparent nutrient deficiencies (primarily iron) and watered only when moisture stress became critical to plant survival.

Depending on weather conditions and day length following seed germination, the total growth period required to produce a containerized seedling ready for outplanting was from 17 to 25 weeks. Gutplanted loblolly pine seedlings averaged 7.5" in height and Virginia pine averaged 6.0".

Outplanting

During the summer of 1981, a reclaimed mine site on Brushy Mountain in Morgan County, Tennessee, was selected for outplanting. The area had been commercially mined and reclaimed following Federal regulations. It had been graded, fertilized and seeded with a legume-grass mixture in the spring of 1981. The reclamation schedule called for tree planting in the spring of 1982. An agreement was arranged with the landowner and the Tennessee

Division of Surface Mine Reclamation to allow this study in lieu of conventional tree planting.

The study site was divided into three blocks, each containing eight treatment plots providing for a factorial arrangement testing the two species, each with and without both disking and mycorrhizal inoculation. The factorial split-plot arrangement enabled the disking of one half of the plots and kept inoculated trees separated from those not inoculated. Each plot was subdivided into eight subplots to which planting dates were randomly assigned. Each subplot contained 20 seedlings planted on the assigned date. Spacing was 3' x 3'.

The survival count on which this analysis is based was made on October 17, 1982, approximately three weeks after the last planting.

RESULTS AND DISCUSSION

Seedling survival for all planting dates and treatment combinations was excellent. Survival was over 90% for all planting dates and treatment conditions (Table 1). Relatively low survival for the July 21 and August 10 plantings (91 and 92 percent, respectively) was largely the result of rabbit damage, without which these values would have been greater than 95 percent.

Although there was a statistically significant (.95 level) survival difference among planting dates, the excellent overall survival makes this of no practical significance. Neither disking nor mycorrhizal inoculation appeared to affect survival. Treatments intended to improve survival cannot provide significant gains when survival without treatment is so high. Unusually well-distributed summer rains appeared to account for this good performance. A more typical season would have greater water stress, possibly resulting in lower overall survival and more significant treatment effects.

Survival will again be recorded at the end of the first winter. After the second summer, both survival and growth measurements will be taken. Treatment effects may be detected at this time, depending on the severity of the winter cold or the summer droughts, or both.

CONCLUSIONS

This study indicates that containerized pine seedlings can be successfully planted throughout the growing season on surface mines in East Tennessee. High survival was obtained even without treatments designed to reduce water stress and improve seedling vigor. Further testing is needed to determine survival in more typical seasons when water stress is more severe.

Table 1.--Seedling survival (percent) according to planting date, species and treatments.

Planting Date	Survival
May 21	97
June 4	98
June 17	96
July 2	95
July 21	91
August 10	92
Sept. 9	98
Sept. 24	97
Species	
Loblolly Pine	97
Virginia Pine	94
Mycorrhizal Inoculation	
Inoculated	95
Control	95
Disking	
Disked	95
Control	96

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REGENERATING RFD OAR ON PRODUCTIVE SITES IN THE

SOUTHERN APPALACHIANS: A **RESEARCH APPROACH**[1/]

David L **Loftis**[2/]

Abstract .--Red oak (Quercus rubra L.) stems in a favorable competitive position are usually absent from recently created even-aged stands, even where red oak was a prominent component of the previous stand. Past research indicates that lack of adequate advance reproduction is the problem on productive sites. A quantitative approach to develop predictive models of regeneration development is outlined. The objectives of this research are to provide: (1) a method of predicting performance of advance reproduction after harvest, and (2) the silvicultural practices which will enhance the development of advance reproduction. Using this information, the manager would be able to maintain red oak as a component in these stands.

Regenerating upland oaks, particularly on good-to-excellent sites, is frequently cited as a management problem in eastern hardwood forests (McLintock 1979, Merritt 1979). In Southern Appalachian mixed hardwood forests. red oak (Quercus rubra) is not being successfully regenerated by even-aged methods (Beck 1970, McGee and Hooper 1975, Loftis 1979). Red oak occurs on good sites in mature stands dominated by red oak and other upland oaks, and on excellent sites where stands are dominated by deciduous species other than oaks. Its rapid diameter growth and high-quality wood make red oak commercially desirable (Fowells 1965). Many wildlife species benefit from its good, though somewhat infrequent, mast production (Beck 1977). We would like to maintain a component of red oak in regenerated stands.

My objectives in this paper are to (1) account for regeneration failures in earlier studies and suggest requirements for success, and (2) outline our approach to red oak regeneration research.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Asheville, N.C.

SOURCES OF REGENERATION

On good-to-excellent sites in the Southern Appalachians red oak often fails to compete after clearcutting, even though it was a prominent component of the overstories of the previous stands, and advance reproduction was present prior to clearcutting (McGee and Hooper 1970, 1975; Beck 1970). After clearcutting, stands are dominated by a mixture of desirable species of seedling and sprout origin and less desirable species mostly of sprout origin. By age 15 to 20 the desirable species, particularly yellow-poplar (Liriodendron tulipifera L.), emerge as dominants. Red oak is rarely among the dominants.

To understand why these oak regeneration failures occur one must consider the sources of regeneration after clearcutting: (1) new seedlings that develop from seed in place or blown or carried in from adjacent stands, (2) seedlings that develop prior to the harvest cut (advance reproduction), and (3) sprouts from stumps and roots of cut trees (Beck 1980). Most hardwoods produce stump sprouts when cut. But Johnson (1977) has shown that for oaks the probability that a stump sprout will become a codominant or dominant component of the new stand decreases with increasing tree diameter. Figure 1 shows a typical diameter distribution for red oak in mature stands in the Southern Appalachians. This sample includes both mixed oak and mixed cove hardwood stands. There were a total of 76 red oak trees 1.5 inches dbh or larger in the sample, of which 58 were sawtimber trees. Applying Johnson's probability estimates to this

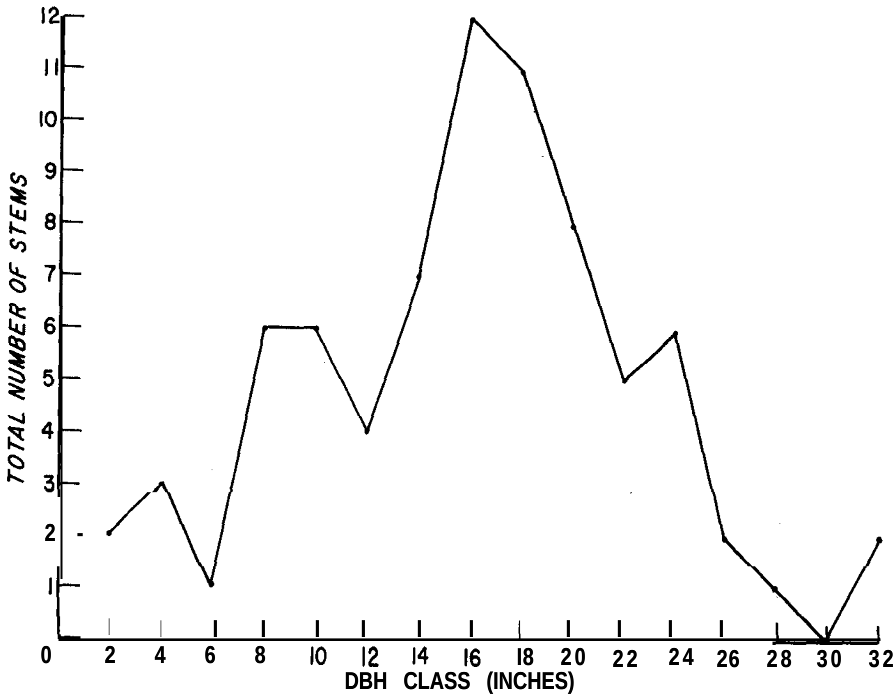

Figure 1 .--Diameter distribution of red oak on plots in mature stands in northeast Georgia.

distribution, we find that if these stands were **clearcut,** stump sprouts would contribute only 12 dominant or codominant stems to the new stands. If we want to have a red oak component in the new stands equal to that in the previous stands (i.e., 58 sawtimber trees), it appears that stump sprouts will contribute far fewer trees than needed.

Several investigators have shown that newly established oak seedlings grow much too **slowly** to compete successfully following clearcutting (Beck 1970, Sander 1972, **McQuilken** 1975). Since new seedlings will not contribute dominant or **codominant** stems to the new stand, and stump sprouts will contribute only a few, advance reproduction will have to be the source of most dominant or codominant stems in the new stand. This opinion is widely held and has become a tenet of oak silviculture (Sander 1971, Sander and Clark 1970, Carve11 and **Tryon** 1961, Merritt 1979).

PREHARVEST ATTRIBUTES OF ADVANCE REPRODUCTION

The presence of oak advance reproduction does not automatically insure oak in the succeeding stand. In a Southern Appalachian clearcut. McGee and **Hooper** (1970, 1975) found an average of 1,450 advance red oak stems per acre. However, this advance reproduction did not **compete** well after harvest. Dominant and codominant red oaks occur infrequently in the new stand.

The first major component of the red oak regeneration problem, then, is to determine what attributes advance reproduction must have **if it** is to compete successfully after overstory removal. Sander **(1971,** 1972) showed that growth of oak advance reproduction after **clearcutting** was related to size of the advance reproduction prior to cutting. Be tentatively concluded that advance reproduction must be at least 4.5 feet tall **prior** to harvest if the succeeding stand is to contain dominant and codominant oaks. Carve11 (1967) found that the vigor of the oak advance reproduction (as measured by the degree of apical dominance expressed) was an important determinant of its growth after release.

To address this first problem component I have established a study with two objectives: (1) to examine the relationships between preharvest attributes of advance reproduction and its post-harvest performance, and (2) to provide useful silvicultural guidelines based on these relationships. Beginning in 1977 I installed a series of plots in mature hardwood stands growing on sites ranging from 65 to 90 site index for oak at 50 years. The plots contained red oak advance reproduction of varying sizes. The advance red oak stems were individually mapped and tagged. Height, basal diameter, and a subjective assessment of apical dominance were recorded for each stem. All plots received a commercial clearcut, and undesirable and unmerchantable stems were treated in one of two ways. **On six** plots these stems were felled after the harvest cut. **On** five plots. they were injected with herbicides prior to harvest. **Our** studies have shown that the character of the young stand will be different in these two treatments. After postharvest felling, sprouts from **undesirable** species will dominate the early life of the stand. With preharvest herbicide treatment advance reproduction and new seedlings will dominate **(Loftis** 1978).

Using standard regression methods, I can relate postharvest growth of individual red oak stems to their preharvest size and apical dominance over a range of site indices. But growth, *per se*, does not give the manager the information he needs. By using the analytical technique applied by Johnson (1977) in his stump sprouting studies, I can provide estimates of the probability that a stem with given preharvest attributes will be a dominant or codominant stem at some time after the harvest cut.

This technique is described in some recent statistics texts (e.g., Neter and Wasserman 1974), and a computer routine to perform the analysis has been developed by Hamilton (1974). The dependent variable is a binary response with a value of 1 if the tree is dominant or codominant and 0 if not. This dependent variable is regressed, using weighted least squares, against the independent variables in a logistic model (fig. 2). The expected value of Y, E(Y), is equal to a probability (p) that Y=1.

The utility of this approach is that it gives the manager a predictive tool. For example, if size is the only important independent variable, an inventory of advance oak reproduction by size classes allows the manager to predict the number of dominant and codominant oak stems in the new stand from an immediate harvest:

$$N = \sum_{i=1}^{r} n_i p_i$$

where: N = predicted number of dominant and codominant red oak stems;

n_i = number of red oak stems in the i^{th} size class;

p_i = probability that a stem in the i^{th} size class will become dominant or codominant.

We can also examine the differences between the two methods of treating unmerchantable stems by testing for differences in our estimates of the parameters of the logistic model (fig. 3).

PROVIDING ADVANCE REPRODUCTION

If the predicted result is acceptable--i.e., the advance reproduction present will provide the desired number of dominant and codominant stems--the manager can proceed with the harvest. However, if the predicted result is not acceptable, then one is faced with the second major component of the problem: how to develop the necessary advance reproduction when it is absent.

Our experience in regeneration studies suggests that while small advance reproduction is commonly found in mature stands, large advance reproduction is rarely present. Moreover, the best data available from the Southern Appalachians suggests that large advance reproduction will not develop in the absence of disturbance. Beck's

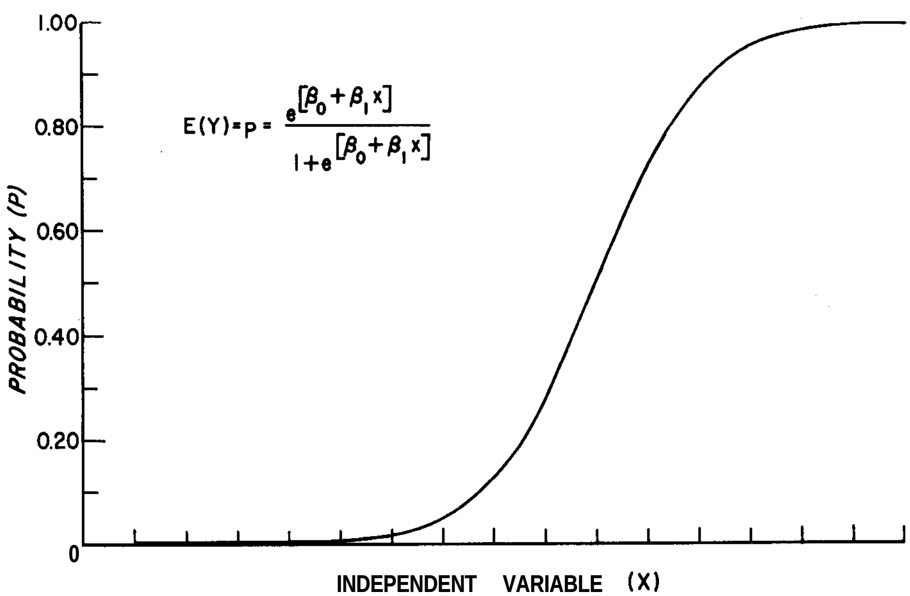

Figure 2.--The logistic function.

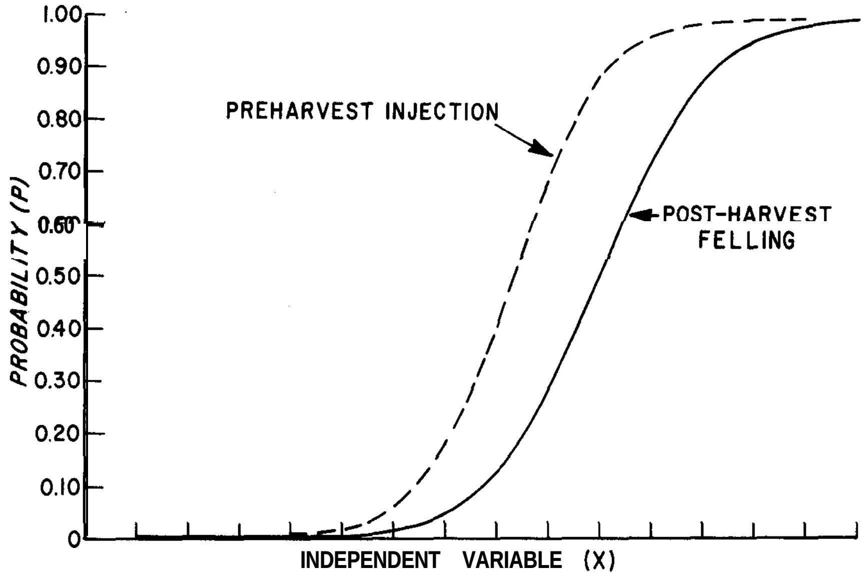

Figure 3.--Hypothesized effect of two methods of treating unmerchantable stems on probability that red oak stems will become dominant or codominant.

study of red oak seedlings (1970) included a sample of seedlings of the same age which were located in undisturbed stands. A graph of survival over time (fig. 4) shows that mortality was high, and after 12 years survival was less than 10 percent. A negative exponential, a common population decay function, fits the data quite well:

$$S_t = S_o e^{-rt}$$

where: S_t = survival of seedlings at t years after establishment

S_o = survival at 0 years, i.e., 100 percent

e = the base of the natural logarithms

r = the rate parameter to be estimated

t = time, in years, after establishment.

Perhaps more important is the graph of height attained over time in these undisturbed stands (fig. 5). The curve might be described by a power function:

$$h_t = \beta_0 t^{\beta_1}$$

where: h_t = mean height of seedlings at t years after establishment

β_0, β_1 = parameters to be estimated

t = time, in years, after establishment.

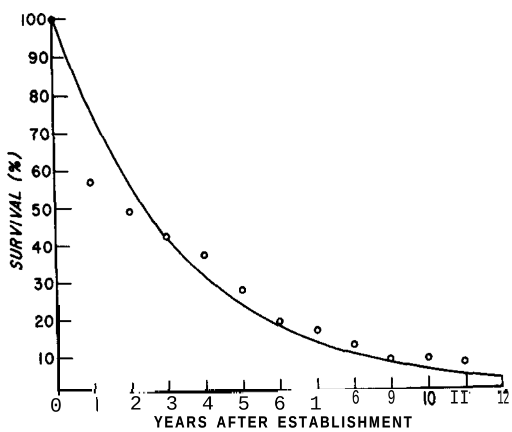

Figure 4.--Survival curve for a cohort of red oak seedlings growing under undisturbed conditions.

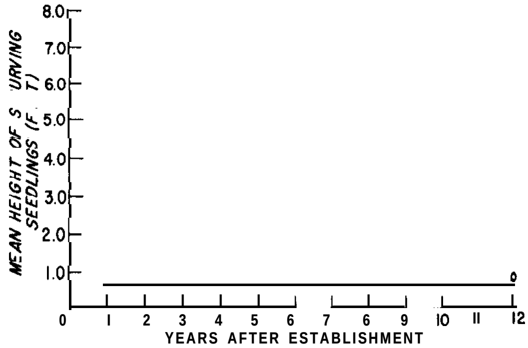

Figure S.--Mean height attained over time by a cohort of red oak seedlings growing under undisturbed conditions.

It appears that leaving stands undisturbed will not result in large advance reproduction being present.

The idea that some action must be taken prior to the end of the rotation to provide advance reproduction is the central concept of the shelterwood regeneration method (Smith 1962). We have made a number of shelterwood cuts on the Bent Creek Experimental Forest near Asheville, North Carolina, with the objective of regenerating oaks. Representative of these cuts is one made on a good site (oak S.I.=84 feet) which supported a mature stand of mixed oak and yellow-poplar. The initial cut removed an average of 50 square feet of basal area per acre in merchantable stems. In addition, 22 square feet of basal area per acre were removed in nonmerchantable, subcanopy stems. The residual stand contained 50 square feet of basal area per acre. There were 2,400 stems per acre of advance red oak reproduction, and 5 years after the initial cut 423 of them had grown to a height of at least 4.5 feet. However, the degree of disturbance in this cut was sufficient to allow associated species, even the most intolerant, to grow as well:

	Stems/acre > 4.5 ft. after 5 years	
Species	Number/acre	Percent
Yellow-poplar	1,720	30
Red oak	423	7
Black cherry	436	8
Other oaks	251	4
Birch	106	2
Other desirables	211	4
Dogwood	940	16
Red maple	606	11
Locust	510	9
Sour-wood	110	2
Other undesirables	417	7

Yellow-poplar seedlings, along with sprouts from the tolerant subcanopy stems, dominated the regeneration after 5 years. Thus, even though red oak advance regeneration responded to basal area reduction, most stems were overtopped by stems of other species.

To favor red oak in regeneration, a shelterwood method should provide for development of large red oak advance reproduction without simultaneously allowing associated species to gain an advantage over the oaks. This goal implies (a) a higher residual overwood basal area to prevent yellow-poplar from becoming established and growing, and (b) eliminating the tolerant subcanopy stems with herbicides to prevent sprouting.

The survival and growth curves from Beck's data could be modified to reflect a basal area reduction (figs. 6 and 7). The rate parameter (r) in the negative exponential curve for survival and the parameters β_0 and β_1 in the curve of growth over time can be estimated as functions of residual basal area:

$$S_t = S_o e^{-r't}$$

where: $r' = f(BA)$

and $h_t = \beta_0' t^{\beta_1'}$

where: $\beta_0', \beta_1' = g(BA)$.

Studies to examine these relationships have been installed in western North Carolina and northeast Georgia. Existing advance oak reproduction on 43 plots has been mapped and tagged. Basal area reductions of 0 to 40 percent of initial basal area (including all stems > 0.5 inches d.b.h.) have been accomplished by stem injection and, in some cases, cutting. In each case, beginning with the smallest diameter classes, untagged stems in successively larger diameter classes were injected until the basal area target for a plot was met.

By measuring survival and growth of these tagged seedlings over time, the relationships between basal area reduction and survival and growth can be established.

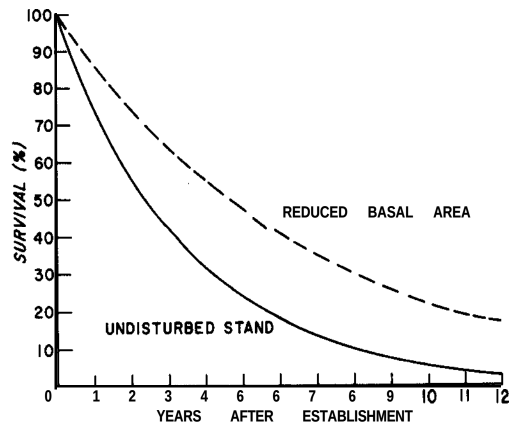

Figure 6.--Hypothesized survival response to a reduction in basal area.

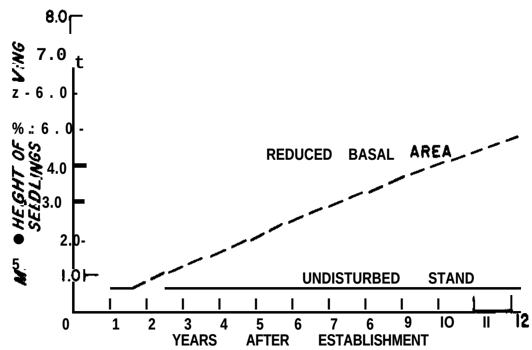

Figure 7.--Hypothesized height response to a reduction in basal area.

SUBCANOPY TREATMENT

We have only recently begun to appreciate how much growing space is occupied by small-diameter stems in mature stands. The majority of these stems, particularly the ones below 7 inches d.b.h., are of tolerant, noncommercial species, and occupy a subcanopy position., Data from my plots in northeast Georgia are typical:

Diameter class	Number of stems	Cumulative BA
-inches-	-per acre-	-% of total-
l-4	446	9.2
5	23	11.4
6	15	13.8
7	13	16.8
8	15	21.2
9	11	25.9
10	11	30.9

The proportion of total stand basal area in these stems is substantial. They contribute to the dense shade under mature stands, preventing growth of advance reproduction of desirable species. If they are cut in the initial cut of a shelterwood or after a commercial clearcut, they sprout vigorously, offering severe competition to desirable species. Eliminating these stems with herbicide injection as part of the initial shelterwood operation seems logical. This treatment removes a source of competition both before and after final overstory removal.

SUMMARY

On good sites in the Southern Appalachians, red oak is not being regenerated by even-aged methods. Stump sprouts and large advance reproduction, the sources for red oak regeneration, are usually absent at the time of clearcutting. Small diameter red oak stems, the best source of stump sprouts, occur infrequently in mature stands. And red oak advance reproduction, when present, is usually too small to compete successfully after harvest.

Studies are now in place to provide predictive models of the performance of red oak advance reproduction after clearcutting, and to develop the silvicultural practices necessary to provide large advance reproduction. The results from these studies should provide managers the guidelines necessary to regenerate red oak on productive sites in the Southern Appalachians.

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SPECIES AND SITE RELATIONSHIPS AMONG OAR REGENERATION TYPES AFTER CLEARCUTTING IN THE VIRGINIA RIDGE AND VALLEY[1]

M. S. Ross, T. L. Sharik, and D. Wm. Smith[2]

Abstract .--The development of oak stems of advance regeneration and stump sprout origin was studied for three years following clearcutting and whole tree removal in southwestern Virginia. Chestnut oak stumps sprouted more frequently and supported taller sprouts than scarlet or black oak stumps. However, shoot growth of advance regeneration did not differ among the three oak species. Taller stump sprouts were associated with more productive sites (as indicated by site index, topographic variables, and vegetation composition). Height growth of oak advance regeneration was also greater on higher quality sites. Both stump size and pre-harvest advance regeneration size had a positive influence on subsequent height growth, although large stumps sprouted more infrequently. Density of well-established oak stems of advance regeneration origin three years after harvest was greatest in stands of site index 55-65, and fell off on sites of higher and lower quality.

INTRODUCTION

In deeply dissected terrain characteristic of steep slopes in the Ridge and Valley Province of southwestern Virginia, site index of upland oaks may change from SI_{50}40 to SI_{50}70 or more within a few hundred feet. Abrupt shifts in site quality are accompanied by equally dramatic changes in species composition in the overstory and understory of 60- to 80-year-old second-growth hardwood/mixed hardwood-pine forests. If intensive harvesting were to occur across this range of sites, differences in growth potential and initial vegetation should be manifested in some way during the early stages of stand regeneration.

On the midslope positions of the generally northeast-southwest-trending ridges, especially on the drier southeast faces, chestnut oak (Quercus prinus L.), scarlet oak (Q. coccinea Muenchh.), and black oak (Q. velutina Lam.) are found in varying proportions on most sites. Because of the dominance and ubiquity of these species in typical second-growth stands, and because of the recent concern with oak regeneration (Holt and Fisher, eds., 1979), the authors investigated the early response of these three species to whole-tree removal. Oak regeneration was studied against the mosaic of growth potential and species composition typical of the region, and the development of oak species was put in context of stand development as a whole.

STUDY AREA

The study area is located at about 760 m elevation on the southeast face of Potts Mountain in Craig County, Virginia. Parent materials are nutrient-poor sandstones and shales, which form coarse-textured, shallow, strongly leached soils. Slopes are generally 30-40 percent. Annual precipitation averages 965 mm, and is evenly distributed through the year. The frost-free season is about 160 days.

Within the study area, oaks were most prominent in the canopies of stands on the broad side slopes, but were subordinate to pitch pine (Pinus rigida Mill.) on south-facing spur ridges, and less abundant than red maple (Acer rubrum L.) in the shallow coves. This range of sites was

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divided into four types on the basis of vegetation composition, as follows: (1) mixed hardwood, with overstory consisting of a variety of relatively mesic species, including red maple, yellow-poplar (Liridondron tulipifera L.) and northern red oak (Quercus rubra L.), shrub stratum poorly developed, and herb layer well-developed and diverse, but largely devoid of ericads; (2) mixed oak, with overstory predominantly oak, and ericaceous understory discontinuous; (3) mixed oak-pine, characterized by an overstory mostly of oaks, but with scattered pine, and a well developed shrub component dominated by mountain laurel (Kalmia latifolia L.), huckleberry (Gaylussacia baccata (Wang) K. Koch) and blueberries (Vaccinium spp.); and (4) mixed pine, with overstory dominated by pines, oaks in a slightly subordinate position, and a heavy shrub layer predominantly of ericads and bear oak (Quercus ilicifolia Wang.) (McEvoy et al. 1980).

The classification of stands according to vegetation composition produced groups which also differed in terms of site productivity. When three separate indices of productivity were applied to the four vegetation types, a gradient of increasing growth potential was evident, in the order mixed pine, mixed oak-pine, mixed oak, and mixed hardwood (Table 1). The productivity gradient was closely associated with soil moisture availability during the 1981 growing season (Meiners 1982).

METHODS

Stump Sprout Development

Eight 1600 m^2 plots and two smaller plots (800 m2 and 400 m^2) were established in the fall of 1977 and the spring of 1978. The plots were situated within three non-contiguous management units totaling 61 ha and extending over 5.3 km distance. One plot was representative of the mixed hardwood vegetation type, while mixed oak, mixed oak-pine, and mixed pine vegetation types were each represented by three plots. At the time of plot establishment, all oak stems greater than 5 m in height were identified, tagged at the base, and located on a coordinate grid. A total of 778 oak stems were tagged at this time.

Between August 1978 and March 1979, all stems greater than 1.5 m in height were cut back to within 15 cm of ground level, and removed from the plots. Removal was by commercial whole-tree harvesting with a cable logging system. Shortly after each unit was cleared, inside bark diameter was determined to the nearest centimeter for each tagged oak.

The schedule of cutting was such that all plots except one were cut during the dormant season. Oak stumps in that area (harvested on August 15) resprouted in September and October, but all sprouts were killed by frost before winter.

In March 1982, following the third growing season after harvest, each tagged stump was assessed for the presence of living sprouts. The height of the tallest sprout was also recorded for a subsample of 305 sprouting stumps. Stump selection was made using a stratified random sampling scheme described below in conjunction with the development of the stands as a whole.

Table 1.--Productivity indices for the four vegetation types included in the study (Potts Mountain, Craig County, VA) (Ross et al. 1982).

Vegetation Type	Number of Stands Represented	Forest Productivity Index1/	Site Index2/	Basal Area Increment /Tree3/ (cm2)
Mixed pine	3	5.3	37	46
Mixed oak-pine	1	8.0	49	44
Mixed oak	3	9.3	59	65
Mixed hardwood	1	14.0	71	67

1/ Based on aspect, slope percent and slope position. High value indicates high potential productivity (Wathen 1977).

2/ Based on total height for upland oaks at age 50 (Olson 1959).

3/ During 1969-1979 period.

Advance Regeneration Development

After the harvesting operation was completed in each of the ten study areas, the plots were divided into 10 x 10 m cells. At the four corners of each cell, each oak advance regeneration stem within one or two 1 m2 **quadrats** (depending on the density of oak individuals in the plot) was mapped and tagged, and height was measured to the nearest centimeter. A total of 352 stems were tallied in this manner. Means and ranges presented for size or growth of oak advance regeneration are based on the 352 randomly sampled individuals. Because individuals taller than 30 cm were not well represented in the small quadrats. the two largest advance regeneration stems greater than 30 cm in height in each cell were also sampled. Where the effects of original stem size are considered, the additional large individuals are included, and are thus based on a total sample of 518 oak stems.

In October 1980 and November 1981, after the second and third growing seasons, advance regeneration height was remeasured. Stems were classified into one of three categories: dead, resprout (died back and resprouted from within 10 cm of stem base), and intact (maintained expansion of original leader).

Stand Structure Three Years After Harvest

In March 1982, species and height were recorded for each stem taller than 1 m within one or two 5 x 5 m subplots per 10 x 10 m cell. The number of subplots sampled in each cell was based on the variance in stem density; only one subplot per cell was required in the relatively uniform mixed oak plots, while two subplots per cell were needed to obtain stable estimates of density in the other vegetation types.

RESULTS AND DISCUSSION

Stump Sprout Development

The percent of stumps that produced sprouts was generally higher for chestnut oak than its two oak associates (Figure 1). Over the entire study area, chestnut oak sprouting was **72%,** scarlet oak **65%,** and black oak 48%. The data illustrated in Figure 1 also indicates that sprouting frequency for all three species was higher in the drier mixed pine and mixed oak-pine vegetation types than on the higher quality sites. However, because a maximum of three replicates of each vegetation type was sampled, and because of the confounding effects of stump size, no statistical certainty could be attached to this apparent trend.

Large chestnut oak stumps were less likely to produce sprouts than stumps 20 cm basal diameter or less (Table 2). However, sprouts produced by stumps 20-30 cm in diameter grew faster in height than sprouts of smaller stumps. If maximization of sprout frequency and vigor were desired, harvest when most stems were in the **10-30** cm range would probably be best.

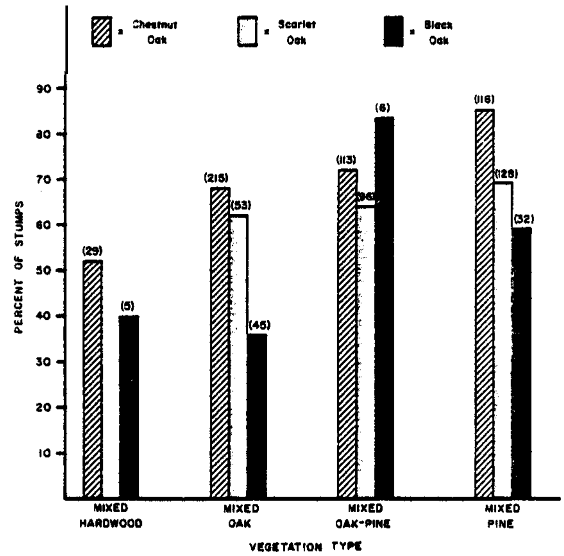

Figure 1. --Percent of stumps which supported at least one sprout three years after harvest on Potts Mountain, Craig County, VA. Numbers in parentheses are number of stumps sampled.

In addition to being the most dependable sprout producer, chestnut oak produced taller sprouts than scarlet or black oak (fig. 2). Averaged over all vegetation types, chestnut oak sprouts were 2.3 m tall, scarlet oak 1.7 m, and black oak 1.7 m in height. The effect of site quality is less consistent than the effect of species, with the mixed oak-pine vegetation type containing significantly shorter sprouts (α = .05) for all

Table 2 .--Frequency of sprouting and height of tallest sprout of four size classes of chestnut oak stumps on Potts Mountain, Craig County, VA.

Stump Diameter	Sprouting Frequency	Sprout Height
(cm)	(%)	(m)
0 - 10	77	2.0a 1/
11 - 20	79	2.4b
21 - 30	71	2.7c
31 - 40	50	2.6bc

1/ Heights followed by different letters differ at alpha = .05.

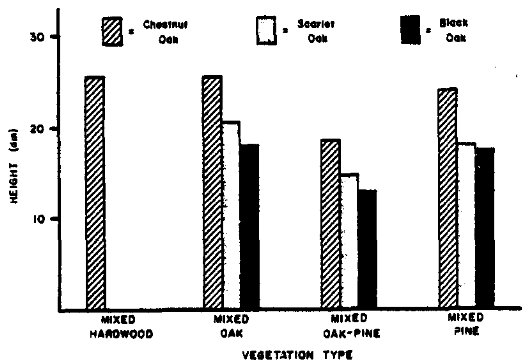

Figure 2.--Mean height for tallest sprout per stump three years after harvest on Potts Mountain, Craig County, VA.

three species than each of the other types, including the lower quality mixed pine type. Once the developing stands reach full site occupancy, available resources are expected to become more limiting, and the effect of site quality to become more firmly established. Continuing long-term study of these areas should help to clarify the point.

Advance Regeneration Development

By the end of the third growing season after harvest, approximately 50 percent of all advance regeneration stems had either died (15 percent) or died back and resprouted (35 percent) (fig. 3). These proportions varied little among species or among vegetation types.

The three oak species also did not differ in height growth, which averaged 20-30 cm over the three-year period (fig. 4). Site quality had a significant effect on chestnut oak height growth, with growth averaging 29 cm and 18 cm on medium and poor quality sites, respectively (fig. 4).

Because of the effect of original stem size on subsequent elongation, average figures for height growth are somewhat misleading. Stems 20 cm or less at the time of harvest grew less than 20 cm over the three-year study period, while larger stems averaged about 60 cm height growth (fig. 5). Stem height three years after harvest was similar for resprout and intact stems, provided they were comparable in height prior to harvest (fig. 5). The idea of a threshold size below which oak advance regeneration will not contribute to the developing forest canopy has been suggested (Sander 1972; Sander et al. 1976). However, the present results indicate that, on poor and medium quality sites typical of the Ridge and Valley, advance regeneration as small as 20-30 cm has considerable potential for height growth.

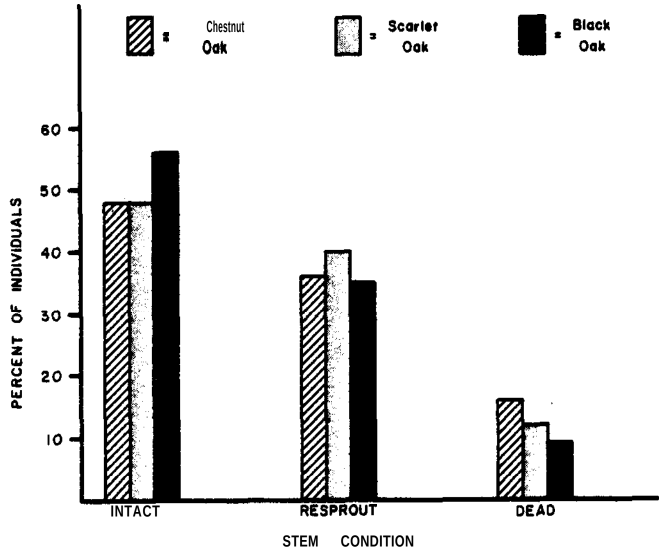

Figure 3.--Condition of oak advance regeneration three years after overstory removal (Potts Mountain, Craig Co., VA). Tops of "resprout" stems had died back and sprouted from within 10 cm of stem base; "intact" stems maintained expansion of original top (n = 268, 52, and 32 for chestnut, scarlet, and black oak, respectively).

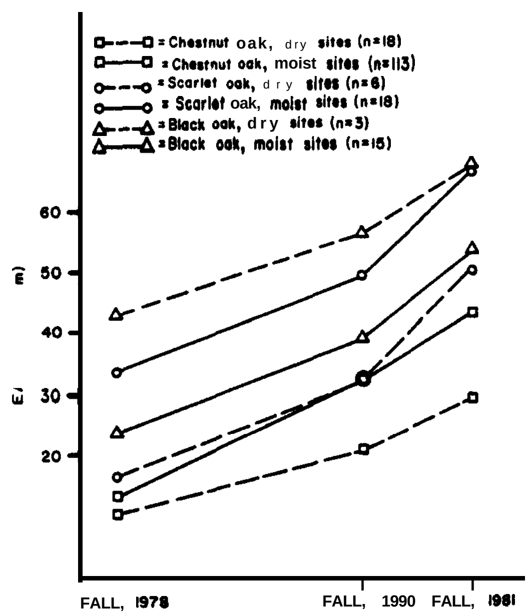

Figure 4.--Height development of intact advance regeneration during first three years after harvest on Potts Mountain, Craig County, VA.

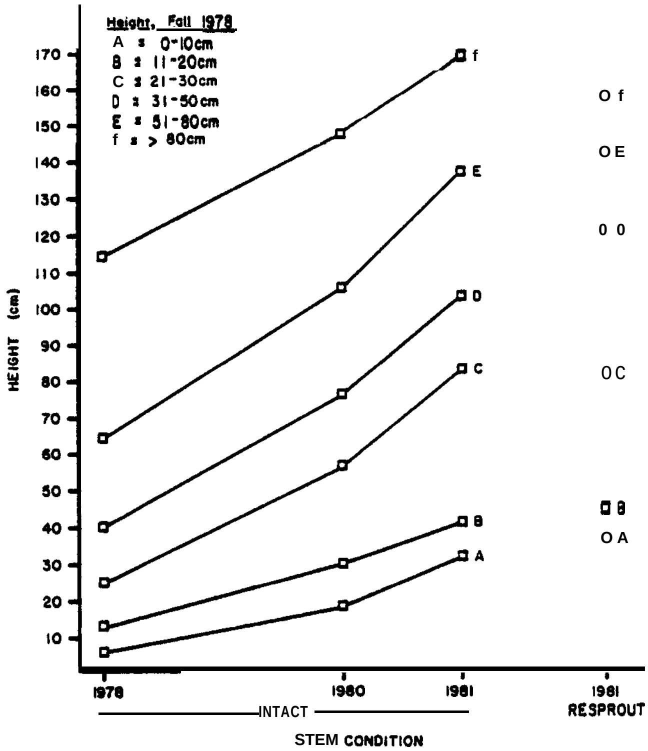

Figure 5.--Height development of six size classes of oak advance regeneration on Potts Mountain, Craig County, VA. Data for chestnut, scarlet and black oak are combined (n = 501).

Stand Structure Three Years After Harvest

The profile diagrams (fig. 6) illustrate the two-tiered nature of the young stands, and the accelerated rate of stand development with increasing site quality. Again, the unexpectedly slow development of the mixed oak-pine areas is evident. The authors anticipate that the fast-developing lower stratum of sassafras, blackgum, and dogwood on medium quality sites will act as "trainers" for the dominant sprouts, and lead to better stem form. In contrast, sprout clumps on poor sites, with little competition from the side, will probably expand to dominate large areas, and eventually give the stand a "wolfy", understocked appearance. Based on annual sampling of the 0-l m height stratum (not shown in figure 6), it is expected that narrow-crowned pines will continue to seed in from adjacent stands, and occupy some of the interstices among the sprouts. In the mixed oak vegetation type, a considerable number of advance regeneration-origin oaks appear to be vigorous and well-positioned enough to reach the forest canopy. In the mixed hardwood stands, where pre-harvest oak advance regeneration was numerous but extremely small in stature, the emergence of some yellow-poplar and blackgum stems from their current subordinate positions to occupy gaps in the canopy is expected.

CONCLUSIONS

After witnessing oak development and stand development in the Virginia Ridge and Valley over the past four years, we regard the problems and prospects of successful oak regeneration to be three-parted. On exposed slopes and ridges, and steep south and southwest aspects (SI_{50} 50 and less) oak advance regeneration stems are not plentiful, either because of competition from ericaceous shrubs, poor seedbed conditions, animal predation, or a host of other possibilities. The problem for oak silviculturists on such sites is seedling establishment prior to harvest, with little regard for attaining great seedling size. On backslopes of east and southeast aspect (SI_{50} 50-65), adequate oak advance regeneration of sufficient stature is generally present to produce full stocking of oak early in stand development. These sites pose few oak regeneration problems. In cove and toe-slope positions, and possibly on north and northeast aspects (SI_{50} 70 and greater), oak advance regeneration may be numerous if an adequate seed source exists. However, these individuals tend to be very small, and will be at a disadvantage in the extremely competitive post-harvest environment on good sites. The silvicultural challenge on good sites is to nurture seedlings of considerable size prior to harvest. Our results indicate that oak advance regeneration stems a half-meter or so in height have a reasonable chance of survival; however, their long-term competitiveness and ability to eventually emerge as dominants in the stand is yet unknown. In order to integrate the site-specific nature of oak regeneration problems, future studies should include some consideration of variability among sites.

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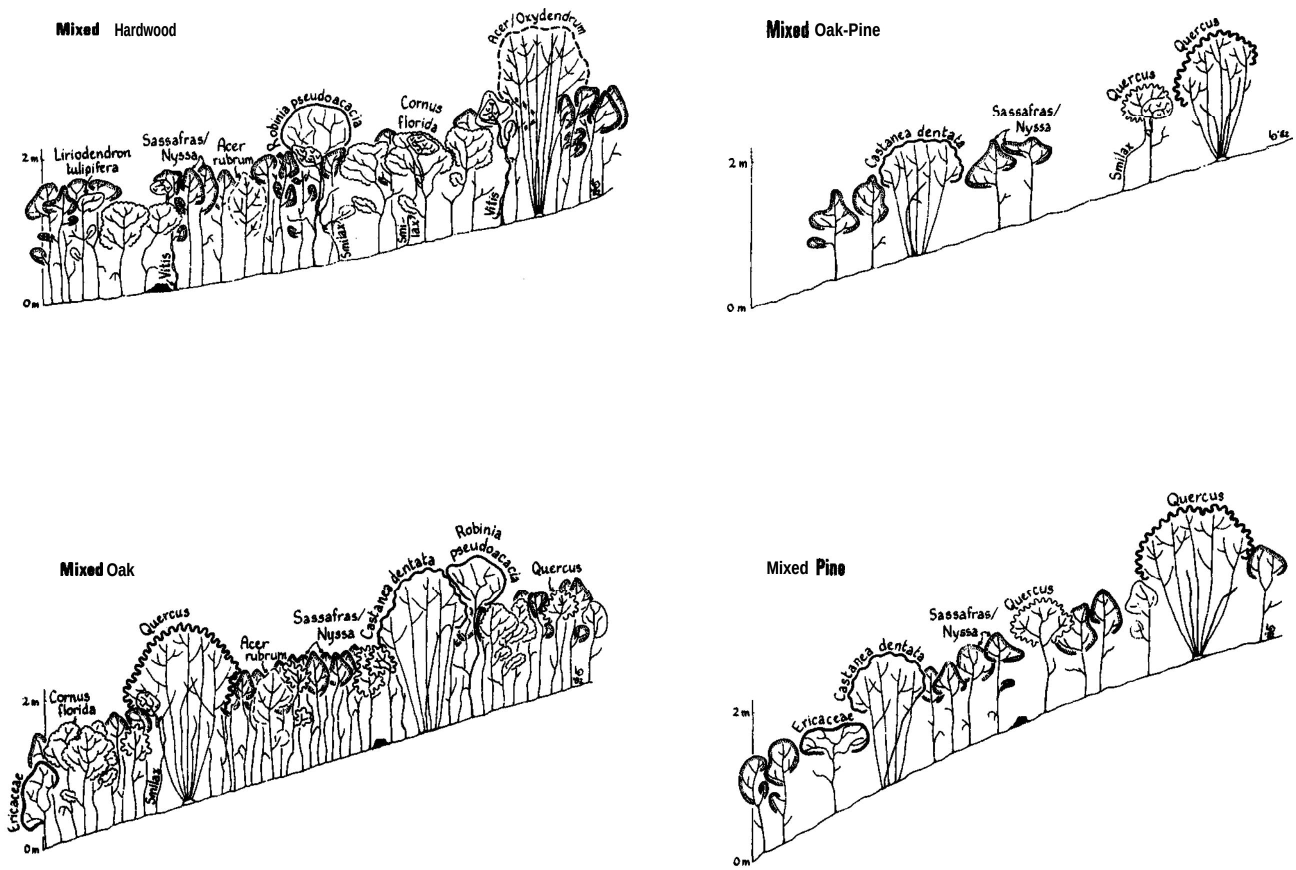

Figure 6.--Profile diagrams of three-year-old stands in four vegetation types on Potts Mountain, Craig County, VA. Height and density for each species group are based on average values in l-5 m height stratum, March 1982. Density: 1 stem = 700 individuals per hectare.

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SUITABLE TREES FOR THE BOTTOMLANDS OF WEST TENNESSEE[1/]

Thomas A. Waldrop, Edward R. Buckner, and Allan E. Houston[2/]

Abstract.--Recent abandonment of agricultural bottomlands in West Tennessee has opened many new areas of productive land for intensive hardwood management. This study examined 3 species; sweetgum, green ash, and sycamore; 2 seed sources for sweetgum and sycamore; and 3 cultural treatments; fertilization, disking, and mowing to determine which combination(s) would be best suited to these sites.

After 3 growing seasons, green ash showed a 98 percent survival rate while sweetgum and sycamore both had 93 percent survival. Survival for all 3 species combined was higher in disked plots (97%) than in mowed (92%) or control plots (94%). Fertilization and seed source had no effect on survival.

Height growth for all 3 species was significantly increased by fertilization and disking. The growth of green ash was increased by 25 percent with fertilization while sycamore and sweetgum growth was increased by 19 and 16 percent, respectively. Gains resulting from disking were 52 percent for sycamore, 50 percent for green ash, and 26 percent for sweetgun. Fertilization and disking combined, did not increase height growth over disking alone. Mowing and seed source had no effect on height growth.

Plantations of either sweetgum, green ash, or sycamore would produce stands of greater value than by natural regeneration. However, significant gains in height growth may be achieved by fertilization and even more by disking.

INTRODUCTION

The high economic return generally realized from soybean production over the past decade, has resulted in the clearing of many stands of bottomland hardwoods along the Mississippi River and its tributaries. While this practice has been economically successful on upper terraces, crops have frequently been lost by flooding on first bottoms. Repeated crop losses on these sites have resulted in the abandonment of significant acreages along tributary streams in West Tennessee (Parsons 1982)[3/]. Without management these highly productive sites commonly restock to low value bottomland hardwoods such as boxelder (Acer negundo L.) and river birch (Betula nigra L.).

The availability of these highly productive lands for forestry use provides a unique opportunity to meet the increasing demand for hardwood pulp, fuelwood and logs for veneer and lumber. Their previous use for agriculture makes them readily assessible for cultural treatments to improve survival and growth.

[1/]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

/Graduate Research Assistant, Professor, and Research Associate, respectively, Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37901.

[3/]Personal interview with David R. Parsons, Fish and Wildlife Biologist, U.S. Department of the Interior, Fish and Wildlife Service.

Although quantitative data on the effects of cultural treatments on the survival and growth of bottomland hardwoods is limited, many forest managers are beginning to intensify their management of these species (Kennedy 1981). Several promising cultural treatments tested to date are fertilization, mowing and disking.

Ammonium nitrate applied at 150 pounds per acre increased the volume nrowth of a six-year-old cottonwood (Populus deltoides L.) plantation by 200 percent (Blackmon and White 1972). Saucier-and Ike (1969) also found that nitrogen fertilization improved the growth of sycamore (Platanus occidentalis L.) and did not have adverse effects on wood properties.

Wowing and disking have been used in intensive hardwood culture primarily to free seedlings from the aggressive herbaceous competition that generally develops on these sites. Kennedy (1981) found that disking increased the height growth of green ash (Fraxinus pennsylvanica Marsh.) by 130 percent while mowing had no significant effect. Survival was also significantly higher in disked plots as compared to either mowed or control plots.

This study was established to evaluate the effectiveness of these three cultural treatments on the survival and growth of selected hardwood species considered to be desirable for plantings on the bottomlands of West Tennessee. As an initial step to this study, sycamore, green ash and sweetgum (Liquidambar styracifula L.) were selected due to their high value on local markets and seedling availability. Other species will be added as seedlings become available.

METHODS

Agricultural lands on the floodplain of a tributary to the Wolf River in Southwest Tennessee were selected for the study. These fields were farmed for soybeans until 1979. Flooding was not an annual problem, however, it occurred often enough that continued cropping was considered risky. Soils were silt loams in which pH ranged from 5.4 to 6.6. Soil tests showed that phosphorus and potassium levels were low for agricultural purposes.

Four replications of a split-plot, randomized complete block design in which five species/seed source combinations (sycamore, green ash, and sweetgum from the Virginia coastal plain and sweetgum and sycamore from the Louisiana Gulf Coast) were tested, with fertilization as the main treatment while disking and mowing were tested at the sub-plot level.

Seedlings were planted in the Spring of 1980. The 5 species/seed sources being tested were represented in each main treatment plot as randomly located sub-plots of 150 seedlings planted in five 30-tree rows on a 10 foot by 10 foot spacing. Since previous studies have shown that fertilization at planting time significantly decreases survival (Buckner and Maki 1977), fertilizer was randomly applied at the beginning of the second growing season to one of the two main-treatment plots in each replication. The three sub-plot treatments (mowing, disking, and control) were randomly applied in each main treatment plot at right angles to the species/seed source plantings.

Fertilization was applied at the rate of 150 pounds of elemental nitrogen per acre and 35 pounds of elemental phosphorus per acre. Specific fertilizers used were ammonium nitrate and triple super phosphate. Disking and mowing were done simultaneously at intervals that would generally keep competing vegetation below 2 to 3 feet in height. This required 5 to 6 mowing/disking operations per year which began in April of the first season following planting and was continued throughout each growing season of the study period.

Survival and tree heights (to nearest 0.5 foot) were measured at the end of the third growing season following planting. Statistical significance was evaluated at the 95 percent confidence level.

RESULTS

Survival

After three growing seasons, survival was above 90 percent for all treatment combinations. This high survival is of particular significance because of adverse weather conditions during the Summer of 1980, the growing season following planting. Record high temperatures and drought made this an exceptionally poor growing season, resulting in the widespread failure of recently established forest plantations.

There were no significant survival differences among the 5 species/seed source combinations. Green ash had the best survival (98%), while it was the same for sweetgum and sycamore (93 percent). Slightly lower survival in fertilized plots (93 percent) was not statistically different from that in unfertilized plots (95 percent). Fertilization at planting time followed by the adverse 1980 growing season would likely have resulted in much greater mortality from this treatment. Survival was 97 percent in disked plots, 94 percent for the controls, and 92 percent in mowed plots. This statistically significant survival advantage in the disked plots was probably related to improved water availability as seedlings became established during the 1980 drought.

Height Growth

Since seed source did not significantly influence height growth within a species, height measurements for **sweetgum** and sycamore from the two sources were combined.

Sycamore was the fastest growing of the species tested with a mean height of 9.0 feet after three growing seasons. This was significantly taller than either green ash (6.1 feet) or **sweetgum** (5.4 feet), between which growth differences were not significant.

The height growth of all three species was significantly increased by fertilization (Table 1). The greatest response was in green ash where fertilized trees were 25 percent taller than those not fertilized. Fertilizers stimulated sycamore and **sweetgum** growth by 19 percent and 16 percent, respectively. **Even** with fertilization the mean heights of green ash (6.7 feet) and **sweetgum** (5.9 feet) were considerably less than that of unfertilized sycamore (8.2 feet).

For all three species disking significantly stimulated growth over the other sub-plot treatments (Table 2). Response was greatest for sycamore (52 percent) followed by green ash (50 percent) and **sweetgum** (26 percent). Mowing did not significantly influence height growth for any of the three species tested.

Figure 1 provides a comparison of the response of the three species to the six combinations of cultural treatments tested. In general,

Table 1.--Mean heights of 3-year-old sweetgum, green ash, and sycamore for fertilized and control plots.

Species	Fertilized (feet)	Control (feet)	Difference (feet)	(%)
Sycamore	9.7	8.2	1.5	(19)
Green Ash	6.7	5.4	1.3	(25)
Sweetgum	7.0	6.0	1.0	(16)

Table 2.--Mean heights of 3-year-old sweetgum, green ash, and sycamore in mowed, **disked,** and control plots.

Species	Control (feet)	Mowed (*) (feet)	Disked (*) (feet)
Sweetgum	5.0	4.7 (-6)	6.3 (26)
Green Ash	5.2	5.2 (0)	7.8 (50)
Sycamore	7.7	7.5 (-2)	11.7 (52)

*Percent change in height as compared to control plot means.

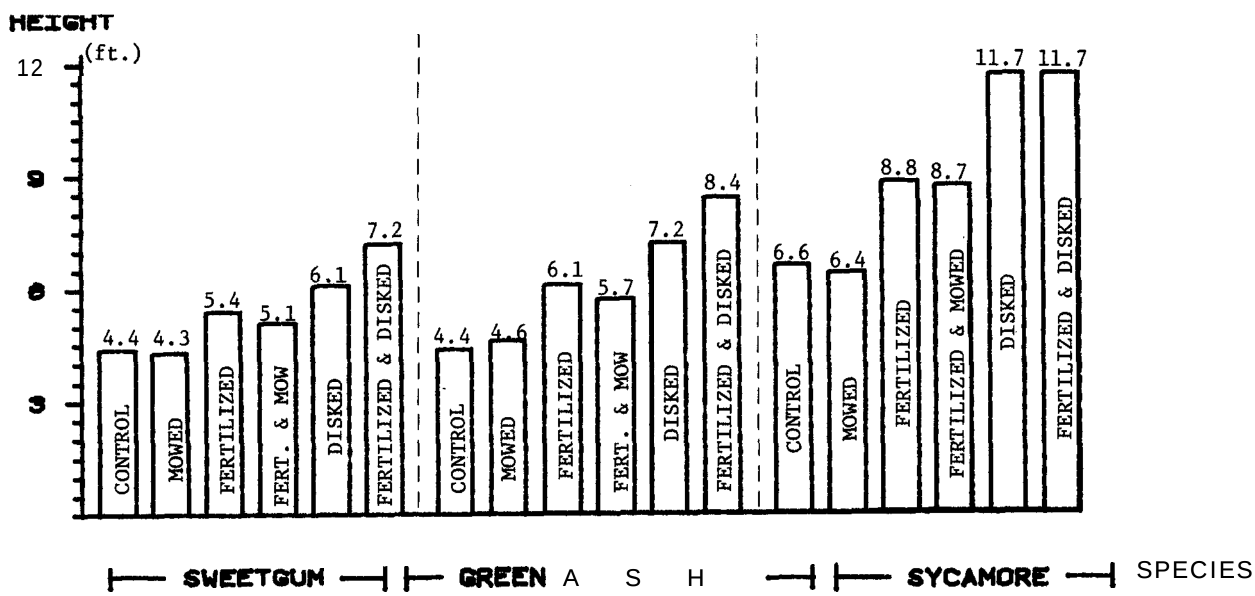

Fig. 4. Mean height of 3-year-old sweetgum, green ash, and sycamore after selected combinations of fertilization, disking, and mowing,

arrangement is according to increasing response, clearly **indicating** that mowing had little or no effect when applied alone or in combination with fertilization. Applied alone, both fertilization and disking significantly increased height growth for all three species. **There** was, however, no significant growth advantage from combining disking and fertilization, especially for sycamore.

DISCUSSION

Since after 3 growing seasons, survival rates for green ash, sweetgum, and sycamore were high for all treatments tested, all would provide fully stocked stands for the bottomlands of West Tennessee.

Disking appears to be the most effective cultural treatment for increasing the early growth rate of all species. Although disking is more expensive than either mowing or fertilization, it can essentially double height growth after three seasons for selected species (e.g. sycamore). For fertilized and/or **disked** sycamore, crown closure will be essentially completed by the end of the fourth growing season. This will eliminate the need for additional treatments to control competing vegetation.

Fertilization also stimulated height growth for all three species. Although disking produced taller trees, the high cost of the repeated on-site activity required for its effective application may make fertilization more economically feasible. There does not appear to be any significant growth advantage from applying both treatments.

Mowing did not significantly increase either survival or height growth for any of the species tested. It did change the composition of competing vegetation from broad leaf weeds to fast growing grasses. This probably increased competition for water and nutrients such that decreased competition for sunlight did not produce the growth gains anticipated. For the conditions tested in this study, mowing is not a recommended practice.

RECOMMENDATIONS

The results of this study suggest that three management intensities can be practically considered for establishing hardwoods on abandoned agricultural lands in West Tennessee. Simply planting to one of the three species tested would establish a stand of desirable hardwoods that should develop into a forest of superior composition and stocking. This would not occur if natural regeneration were relied upon for stand establishment.

A higher level of management would be to fertilize plantations at the beginning of the second growing season. This should result in a significant improvement in height growth for the three species tested, especially for green ash. This combination requires two treatment operations but would likely result in further gains over planting alone in that stand closure would occur earlier. This would reduce the time period over which there is intensive competition from herbaceous weeds.

A further gain can be realized by disking four or five times during the growing season for the first three seasons following planting. While disking appears to eliminate the need for a fertilizer treatment, it does require repeated visits to the plantation for several years, after which stand closure should be sufficient to eliminate the need for further treatment.

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UNDERSTORY LIGHT INTENSITY IN BOTTOMLAND HARDWOOD STANDS[1]

Jim L. Chambers and Michael W. Jenkins[2]

Abstract.--The relationship between understory light levels and several stand characteristics and thinning intensities was studied in five bottomland hardwood species-types. A total of 50 half-acre plots were thinned by removing 0, 12, 24, 36, 48, and 60 percent of the basal area. Light levels were measured in the understory of each plot 6 times during the full leaf portion of the growing season. Percent-thin, percent-crown cover and residual basal area were highly correlated with light levels in the understory. Both percent-thin and percent-crown cover may be useful in making management decisions.

INTRODUCTION

Understory light intensity in hardwood stands has been shown to have a major impact on the growth and survival of planted seedlings, natural seedlings, and herbaceous plants (Logan 1965, Carvell 1966, McGee 1968, Ashby 1976, Duba and Carpenter 1980). Numerous investigators have studied the relationships between various types and levels of thinning and light levels within forest stands. Several of these studies have related understory light levels to size of opening produced from thinning or patch clear-cutting (Jackson 1959, Minckler 1961, and Marquis 1965).

Working in upland hardwood stands having a limited range of basal areas, Minckler (1961) found understory light levels to be closely related to residual basal area in the stand. Ashton (1958) indicated that second-story vegetation density significantly affected the amount and kind of understory light. Ovington and Madgwick (1959) noted a reduction in light levels at the forest floor as canopy depth increased.

Little information is available illustrating the effects of thinning on understory light levels in bottomland hardwood stands, even though information concerning the effects of thinning on understory light levels in bottomland hardwood stands would be a valuable aid in planning for natural regeneration. Such knowledge could also be utilized to favor certain understory tree species, or to modify overstories serving as nurse crops for newly planted seedlings. It could also be used to evaluate the effects of thinning practices on production of wildlife food species.

The objectives of the paper are to: (1) discuss the relationships of understory light levels to several overstory stand characteristics and thinning intensities in five bottomland hardwood species-types and (2) describe the potential uses of these variables in determining the levels of thinning necessary for successful natural and artificial hardwood regeneration.

METHODS AND PROCEDURES

Study Areas

Study plots were chosen from four areas in Louisiana. Areas chosen included the Louisiana State University (LSU) Ben Hur Research Farm and the LSU Burden Research area near Baton Rouge in south central Louisiana, the LSU Idlewild Experiment Station near Clinton in south central Louisiana, and LSU School of Forestry and Wildlife Management Lee Memorial Forest near Sheridan in the east central part of the state.

Plot Selection

Initial reconnaissance of the study areas yielded five potential species-types (based on species dominance) that could be included in the study. Within each species-type, ten half-acre (0.20 ha) plots were selected over a broad range of available basal areas. All vegetation with a

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dbh (diameter at 4.5 ft, 1.3 m, above the ground) of less than 4.0 inches (10.0 cm) was removed by severing the stem near ground line. Removal of small stems was done to eliminate the second-story vegetation for an underplanting study to take place on these plots. Location of trees greater than 4.0 inches (10 cm) dbh was mapped for each plot. The dbh and basal area of each tree was included on the plot maps to aid in the thinning process.

Five levels of thinning were applied to each species-type. Plots were to be thinned by removing 12, 24, 36, 48, and 60 percent of the plot basal area from one plot respectively for each species-type. Using plot maps, thinning was planned to maintain relative species composition on each plot and to evenly distribute the basal area removal across each plot.

Measurements

After plots were thinned, the center one-quarter acre (0.10 ha) of each plot was delineated on the ground for the measurement of light levels within the plot. Light measurements were taken at 25 systematically spaced (25 X 25 ft, 7.6 X 7.6 m) sample locations on each plot. A LI-COR model LI-185 light meter and quantum sensor were used to measure light levels in the photosynthetically active range (0.4 to 0.7 μ E m^{-2} s^{-1}). The light measurement period extended from 10 August 1981 to 5 September 1981 and from 1 June 1982 to 20 July 1982. Light measurements were gathered on each plot once during each two week period for a total of six sampling days on each plot. All light measurements were made between 9:30 am and 2:30 pm C.S.T. to reduce the effects of adjacent unthinned forest areas. On each sample day, full light was determined by taking the average of light readings made in the open before and after light was measured in each forested plot.

Total height, depth of live crown and dbh were measured for each tree left on each plot after thinning. A spherical densiometer (Lemmon 1956) was used to determine the percent crown cover on each plot. Densiometer readings were taken at the 25 light measurement locations on each plot and an average value was then calculated for each plot.

RESULTS AND DISCUSSION

Based on measurements from the 50 experimental plots over 5 species-types a broad range of stand conditions and thinning intensities were included in this study (Table 1). The broad range of data included in this study should make the results applicable over a broad range of conditions.

General thinning guides often specify cutting to certain basal areas for a given stand age and site index based on a percent of the maximum achievable basal area a particular species naturally obtains. Since basal areas for natural stands of previously cutover timber often vary widely, we decided to look at the relationship between understory light levels and basal area on the 25 unthinned plots used in this study. A plot of the understory light levels as a percent of the light in the open (percent

Table 1. Range and mean of several stand characteristics for 50 measurement plots in bottomland hardwood stands included in the study.

Statistic	Percent Light in Understory[a]	Light levels Above Canopy in $\mu E\ m^{-2} s^{-1}$	Thinning Level in Percent[b]	Crown Cover in Percent	Average Stand Height in meters (feet)	Crown Depth in meters (feet)	Pre-thinning Basal Area in $m^2\ ha^{-1}$ ($ft^2\ ac^{-1}$)	Number of Trees per ha (ac)
Minimum	**2.4**	**202.8**	0.0	52.1	14.6 (47.8)	(2 %	19.8 (86.2)	325 (131)
Mean	**18.8**	**1662.0**	18.1	80.9	17.9 (58.7)	**8.6 (28.3)**	34.5 (149.6)	474 **(191)**
Maximum	90.1	2215.0	64.6	93.6	22.1 (72.5)	10.7 (35.1)	46.2 (201.0)	695 **(281)**

[a] **Understory** light as a percent of light measured in the open.

[b] **Thinning** levels as a percent of the basal area removed.

light) against basal area in the unthinned plots indicated little if any relationship between these variables (Figure 1). Correlation analysis between these variables resulted in a correlation (r) of 0.019. A test of the null hypothesis, that correlation coefficient was equal to zero, could not be rejected at the 0.05 alpha level (probability = 0.81).

Next the effects of thinning on percent-light in the understory were examined. A correlation matrix was developed between percent-light and all of the measured stand characteristics (Table 2). The stand variables most highly correlated with percent-light in the understory in the thinned plots were percent-thin (percent of basal area removed) (r=0.789), percent-crown cover (r=-0.786), and residual basal area (r=0.697). Significant differences in correlation coefficients were found by pairwise t-tests of the correlation between percent light in the understory and the three most highly correlated variables. The correlation coefficient between percent-light and percent-thin was significantly higher (α=0.05) than between percent-light and residual basal area. The correlation coefficient between percent-light and percent-crown cover was also significantly higher (α=0.05) than between percent-light and residual basal area. The correlation coefficients between

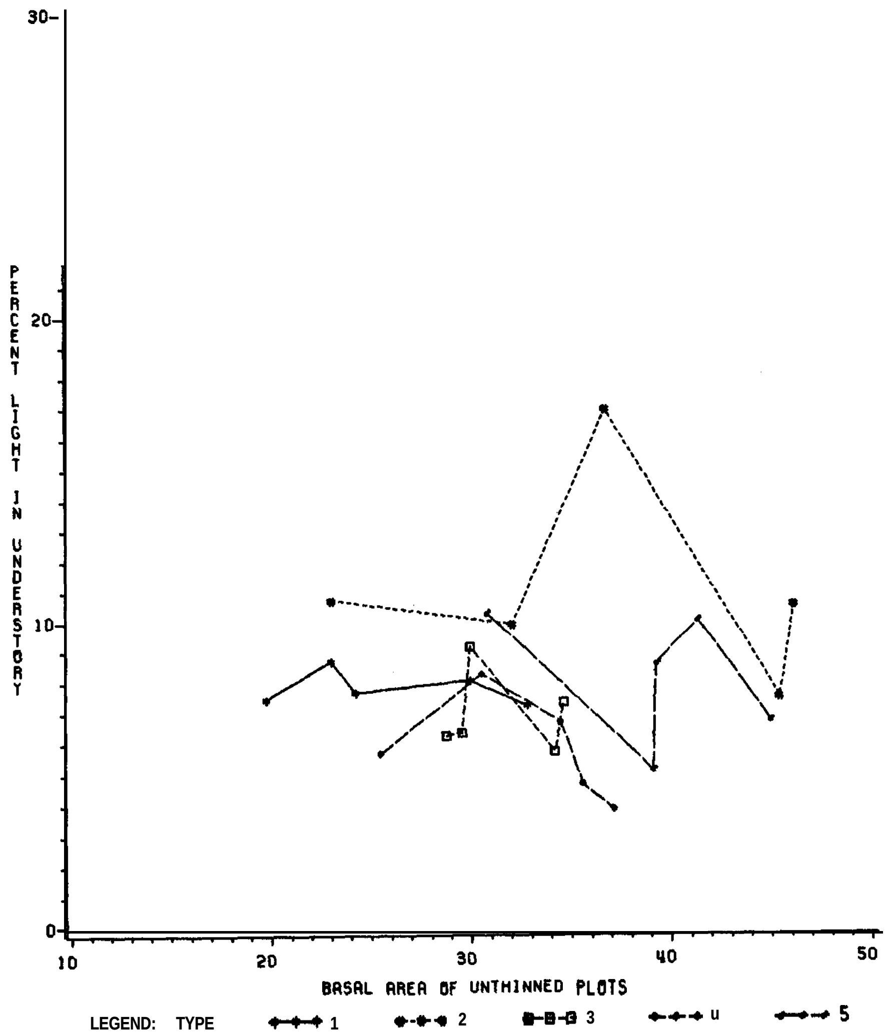

Figure 1.--Plot of percent light in the understory against basal area in the unthinned plots for five species types.

Table 2. Correlation coefficients (top number) and level of significance (bottom number) among measured stand characteristics for all five species-types.

	Percent Light	Percent Thin	Percent Crown	Total Height,	Dbh	Crown Height	Crown Depth	Basal Area Pre-thin	Basal Area Residual	Number of Stems Pre-thin	Number of Stems Residual
Percent Light	1.000 .0000	0.789 .0001	-0.786 .0001	-0.402 .0001	-0.100 .2257	-0.376 .0001	-0.314 .0001	-0.000 .9996	-0.697 .0001	-0.021 .7977	-0.526 .0001
Percent Thin		1.000 .0000	-0.948 .0001	-0.285 .0004	-0.078 .3451	-0.303 .0002	-0.198 .0150	0.037 .6562	-0.853 .0001	0.077 .3483	-0.621 .0001
Percent Crown			1.000 .0000	0.340 .0001	0.088 .2869	0.332 .0001	0.255 .0017	0.034 .6782	0.844 .0001	0.000 .9975	0.640 .0001
Total Height				1.000 .0000	0.487 .0001	0.758 .0001	0.899 .0001	0.234 .0039	0.391 .0001	0.148 .0704	0.160 .0498
Dbh					1.000 .0000	0.298 .0002	0.486 .0001	0.299 .0002	0.207 .0110	-0.386 .0001	-0.272 .0008
Crown Height						1.000 .0000	0.395 .0001	-0.058 .4840	0.270 .0008	-0.091 .2683	0.024 .7670
Crown Depth							1.000 . 0000	0.369 .0001	0.369 .0001	0.270 .0008	0.210 .0099
Pre-thinning Basal Area								1.000 .0000	0.477 .0001	0.681 .0001	0.422 .0001
Residual Basal Area									1.000 . 0000	0.298 .0002	0.651 .0001
Number of Stems Before Thinning										1.000 .0000	0.651 .0001
Number of Stems After Thinning											1.000 .0000

percent-light and percent-thin was not significantly different from the correlation between percent-light and percent-crown cover (α=0.05). Therefore, percent-thin and percent-crown cover are potentially better predictors of understory light and are more closely related to it in thinned stands than residual basal area. Correlation coefficients between percent-light and the three most highly correlated independent variables for each species-type are presented in

The high correlation between percent-thin and percent-light in the understory could make this relationship useful in determining appropriate thinning levels necessary to obtain desirable understory light levels for a variety of purposes. Bottomland hardwood stands with widely different basal areas can and often do have relatively complete crown cover. Therefore, the percent of the basal area removed and percent-crown cover remaining are much better indicators of the amount of light able to penetrate through the canopy in thinned stands than the actual basal area remaining.

Since, percent-thin is easier to apply and requires only a calculation of basal area, we believe it would be a better choice than percent-crown cover as a predictor of understory light levels in thinned stands.

SUMMARY AND CONCLUSIONS

Although there was appreciable variation in understory light levels spatially, diurnally and over the growing season, understory light levels as a percent of light in the open provided a meaningful comparison of light levels under different stand conditions and thinning regimes. Many factors influence light levels in the forest understory. However, when second-story vegetation was removed from the stands in this study, percent-thin and percent-crown cover accounted for more of the variation in understory light levels than any other tested stand characteristics.

Table 3. Correlation coefficients for the relationship between percent light in understory, and percent-thin, percent-crown cover, and residual basal area.

Species-Type[a/]	Percent Thin[b/]	Percent Crown Cover	Residual Basal Area
Sugarberry-Sweetgum-Boxelder (n[c/]=30)	0.87	-0.86	0.84
Red Maple-Green Ash-Swamp Tupelo (n=30)	0.77	-0.78	0.66
Sweetgum-Blue-Beech (n=30)	0.73	-0.71	0.69
American Beech-Swamp Tupelo-Spruce Pine (n-30)	0.88	-0.84	0.81
Swamp Tupelo-Sweetbay (n=30)	0.86	-0.86	0.86
All Species-types (n=150)	0.79	-0.79	0.70

a/ Celtis laevigata Willd-Liquidambar styraciflua L.-Acer negundo L.

Acer rubrum L.-Fraxinus pennsylvanica Marsh. -Nyssa sylvatica var. biflora (Walt.) Sarg.

Liquidambar styraciflua L.-Carpinus caroliniana Walt.

Fagus grandifolia Ehrh.-Nyssa eylvatica var. biflora (Walt.) Sarg.-Pinus glabra Walt.

Nyssa sylvatica var. biflora (Walt.) Sarg.-Magnolia virginaina L.

b/ Thinning levels as a percent of the basal area removed.

c/ n = number of observations

If certain levels of light are desirable in the understory, percent-thin required to approach these light levels could be predicted from the relationships between light and thinning intensities. Furthermore, percent-crown cover may have distinct advantages in assessing the need for rethinning, since, percent crown cover will increase as crowns spread to take advantage of the room left by thinning. More research is needed concerning the relationship between rate of canopy closure and understory light levels.

Residual basal area was not as highly correlated to percent-light' in the understory because of differences in initial stand basal areas and possibly crown closure. For this reason it is suggested that for stands with considerable variation in basal areas but full crown closure that percent-thin or percent-crown cover would probably be better predictors of understory light levels than residual basal area. Furthermore, the practice of cutting back to a given basal area can have highly variable affects on understory light levels in bottomland hardwood stands.

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COMPOSITION AND CHARACTERISTICS OF ADVANCE REPRODUCTION IN THE PURE YELLOW-POPLAR COMPONENT OF COVE HARDWOODS IN THE SOUTHERN APPALACHIANS[1/]

Lino Della-Bianca[2/]

Abstract.--Thirty-six even-aged stands of pure yellow-poplar (Liriodendron tulipifera L.), which were thinned 15 years before at age 60 years or older, were studied to determine kind, amount, and height of advance reproduction. The reproduction consisted of 24 tree species which were over 4.5 feet tall. Total basal area in saplings ranged from 9.8 to 11.5 ft^2/acre; stem numbers ranged from 778 to 1,516 stems/acre. Timber species accounted for 26, 31, and 53 percent of the sapling basal areas on land of site index (feet at age 50) 90, 100, and 110, respectively. Average d.b.h. for timber species was 0.9, 1.5, and 1.6 inches on site index 90, 100, and 110, respectively. The number of saplings of timber species ranged from 288 to 604 stems/acre, and the advance reproduction would best be typed as cove hardwoods. Flowering dogwood (Cornus florida L.) was the most abundant and frequently occurring species on all sites. On sites 100 and 110 yellow-poplar ranked second to flowering dogwood in basal area; on site 90 sweet birch (Betula lenta L.) was the second most prominent species in both stem numbers and basal area. Height of the 280 tallest saplings per acre averaged 22.4 feet and ranged from 10.7 to 36.8 feet. Site index had only a very slight, almost negligible, effect on height of advance reproduction but overstory density affected sapling height considerably; advance reproduction at the lowest residual basal area was 8 feet taller than at the highest.

Intensive management of yellow-poplar stands causes development of advance reproduction, which will have to be reckoned with at the time of the final harvest. The probable composition and size of such reproduction is not known, but at final harvest, two options may exist. All advance reproduction might be cut to the ground or it might be left to form a new stand of quality timber. Much depends upon the species composition.

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Thirty-six even-aged, pure yellow-poplar stands that had been thinned repeatedly were approaching harvestable age and were available for this study. The stands had been thinned 15 years before, when they were 60 years old or more. In this paper I report conclusions drawn from observations in these stands. And from sampling data, estimates are given of the kind, amount, and height of tree species comprising advance reproduction in these stands.

METHOD

One 0.25-acre circular plot corrected for slope was located in each of 36 stands in the Southern Appalachians from Georgia to Virginia. Each plot was surrounded with a 33-foot buffer zone thinned in the same manner as the plot. Advance reproduction of all species was cut to ground level immediately after thinning. Residual basal area ranged from 50 to 130 ft^2/acre for the site index 90 and 100 plots, and 50 to 150 for site index 110 plots.

Two randomly located 0.025-acre circular subplots were used to assess development of understory vegetation in the thinned plots. The subplot centers were randomly located in the major plot within a circular zone which had maximum and minimum radii of 40 and 20 feet, respectively, to ensure that the subplots would be contained entirely within the major plot. Within each subplot, the species and d.b.h. of every sapling (stem over 4.5 feet tall) was recorded. Each stem in sprout clumps and all single stems were tallied; no maximum size was set for these stems that had developed since thinning. In addition, total height of the 7 tallest saplings per subplot (280 saplings per acre) was measured to approximate the number of future crop trees.

Multiple regression was planned for analysis of the basic field data, but scatter diagrams and low R^2 values for six regression equations showed the futility of such an analysis. Accordingly, the data were stratified into site index classes of 90, 100, and 110 feet at age 50 years and presented in tabular form.

RESULTS

Saplings of 24 tree species occurred on the 36 plots. Tables 1 and 2 present density relationships, composition, and frequency by site for stem numbers/acre and basal area/acre, respectively. Numbers of saplings decreased with increasing site quality because faster stem growth on the better sites increased mortality due to suppression.

Table 1.--Density and frequency relationships by site for advance reproduction in thinned even-age yellow-poplar stands 60 years or older.

Species	Site 90 (N = 14)			Site 100 (N = 13)			Site 110 (N = 9)		
	Density	Relative density	Freq.	Density	Relative density	Freq.	Density	Relative density	Freq.
	No. stems/acre	%	%	No. stems/acre	%	%	No. stems/acre	%	%
Ash spp. (*Fraxinus* L.)	11.4	0.5	29	12.3	0.8	23	4.4	0.4	22
Black cherry (*Prunus serotina* Ehrh.)	1.4	0.1	7	--	--	--	--	--	--
Black locust (*Robinia pseudoacacia* L.)	62.9	3.0	57	43.1	2.8	46	68.9	5.8	44
Black oak (*Quercus velutina* Lam.)	5.7	0.3	7	--	--	--	--	--	--
Eastern hemlock (*Tsuga canadensis* (L.) Carr.)	50.4	2.4	29	3.1	0.2	8	6.7	0.6	11
Flowering dogwood (*Cornus florida* L.)	1,415.7	66.6	86	912.3	58.3	92	720.0	60.0	78
Hickory spp. (*Carya* Nutt.)	50.0	2.4	64	10.8	0.7	31	33.3	2.8	44
Northern red oak (*Quercus rubra* L.)	27.1	1.3	29	4.6	0.3	23	6.7	0.6	22
Red maple (*Acer rubrum* L.)	15.7	0.7	43	27.7	1.8	46	17.8	1.5	22
Sugar maple (*Acer saccharum* Marsh.)	--	--	--	50.8	3.3	15	--	--	--
Sweet birch (*Betula lenta* L.)	342.9	16.1	57	32.3	2.1	46	217.8	16.1	78
White basswood (*Tilia heterophylla* Vent.)	--	--	--	3.1	0.2	8	2.2	0.2	11
White oak (*Quercus alba* L.)	4.3	0.2	21	--	--	--	4.4	0.4	11
Yellow-poplar (*Liriodendron tulipifera* L.)	32.9	1.6	57	100.0	6.4	85	57.8	4.8	67
Other 1/	99.6	4.6	--	360.0	23.1	--	57.7	4.8	--
Total	2.120.0	100.0		1,560.1	100.0		1.197.7	100.0	

1/ Other includes: American chestnut (*Castanea dentata* (Marsh.) Borkh.), American hornbeam (*Carpinus caroliniana* Welt.), blackgum (*Nyssa sylvatica* Marsh.), butternut (*Juglans cinerea* L.), Carolina silverbell (*Halesia carolina* L.), cucumbertree (*Magnolia acuminate* L.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch). Fraser magnolia (*Magnolia fraseri* Walt.), sassafras (*Sassafras albidum* (Nutt.) Nees), sourwood (*Oxydendrum arboreum* (L.) DC), spice-bush (*Lindera benzoin* (L.) Blume.), wild grape spp. (*Vitis* L.).

Table 2.--Basal area relationships by site for advance reproduction in thinned even-age yellow-poplar stands 60 years or older.

Species	Site 90 (N = 14)		Site 100 (N = 13)		Site 110 (N = 9)	
	Basal area	Relative basal area	Basal area	Relative basal area	Basal area	Relative basal area
	Ft²/acre	%	Ft²/acre	%	Ft²/acre	%
Ash spp. (Fraxinus L.)	0.1280	1.31	0.0160	0.14	0.0120	0.11
Black cherry (Prunus serotina Ehrh.)	0.0060	0.06	--	--	--	--
Black locust (Robinia pseudoacacia L.)	0.4040	4.14	0.7200	6.24	1.4240	13.47
Black oak (Quercus velutina Lam.)	0.0080	0.08	--	--	--	--
Eastern hemlock (Tsuga canadensis (L.) Carr.)	0.2900	2.97	0.0120	0.10	0.0140	0.13
Flowering dogwood (Cornus florida L.)	5.7200	58.67	6.3920	55.40	4.6300	43.80
Hickory spp. (Carya Nutt.)	0.1080	1.11	0.0320	0.28	0.2140	2.02
Northern red oak (Quercus rubra L.)	0.2200	2.26	0.0240	0.21	0.1360	1.29
Red maple (Acer rubrum L.)	0.0600	0.62	0.2500	2.17	0.2860	2.71
Sugar maple (Acer saccharum Marsh.)	--	--	0.3020	2.62	--	--
Sweet birch (Betula lenta L.)	0.9660	9.91	0.0520	0.45	1.1940	11.30
White basswood (Tilia heterophylla Vent.)	--	--	0.0700	0.61	0.0004	0.01
White oak (Quercus alba L.)	0.0240	0.25	--	--	0.0080	0.08
Yellow-poplar (Liriodendron tulipifera L.)	0.3560	3.65	2.0480	17.76	2.2860	21.63
Other [1]	1.4600	14.97	1.6148	14.02	0.3640	3.45
Total	9.7500	100.00	11.5328	100.00	10.5684	100.00

[1] Other includes: American chestnut ((Castanea dentata (Marsh.) Borkh.), American hornbeam (Carpinus caroliniana Walt.). blackgum (Nyssa sylvatica Marsh.), butternut (Juglans cinerea L.), Carolina silverbell (Halesia carolina L.), cucumbertree (Magnolia acuminata L.), eastern hophornbeam (Ostrya virginiana (Mill.) K. Koch), Fraser magnolia (Magnolia fraseri Walt.), sassafras (Sassafras albidum (Nutt.) Nees), sourwood (Oxydendrum arboreum (L.) DC.), spice-bush (Lindera benzoin (L.) Blume.), wild grape spp. (Vitis L.).

Basal area of advance reproduction ranged from 9.8 to 11.5 ft²/acre. It and the proportion of it in timber species increased with site index. Timber species made up 26, 31, and 53 percent of the sapling basal area on sites 90, 100, and 110, respectively. Tree species making up less than 1 percent of the basal area included American chestnut, black cherry, blackgum, black oak, butternut, Carolina basswood, eastern hophornbeam, and white oak. The average d.b.h. for saplings of timber species was 0.9, 1.5, and 1.6 inches on sites 90, 100, and 110, respectively; for other species it was 0.9, 1.1, and 1.1 inches.

Flowering dogwood.--Flowering dogwood was the most abundant and common species in advance reproduction on all sites, it averaged 1,060 stems/acre and occurred on 86 percent of the plots. The basal area in flowering dogwood averaged 5.7 ft²/acre, and made up 54 percent of sapling basal area.

Yellow-poplar.--Yellow-poplar saplings were not present on 31 percent of the study plots, even though from 16 to 74 percent of the overstory yellow-poplar trees had been cut in thinning these particular plots. Where yellow-poplar reproduction was present, its saplings ranged from 20 to 340 stems/acre in plots from which 6 to 75 percent of the trees were cut.

Abundance of yellow-poplar reproduction increased with site index, and averaged 60 stems/acre with a frequency of 70 percent. Basal area in yellow-poplar averaged 1.4 ft²/acre; its relative basal area was 13 percent. On site 100 where yellow-poplar was most abundant, the relative density of timber species was least, amounting to only 18 percent of the reproduction. On sites 100 and 110, yellow-poplar ranked second to flowering dogwood in basal area.

Sweet birch.--Sweet birch was the second most prominent species on site 90 in both stem numbers and basal area. Its frequency was 58 percent, and an average of 199 stems/acre were present.

Black locust.--Black locust ranked third in basal area to flowering dogwood and after yellow-poplar on sites 100 and 110. Its basal area averaged 0.8 ft^2/acre, which was 7 percent of sapling basal area.

Northern red oak.--Frequency of occurrence of northern red oak was relatively consistent by site, averaging 25 percent. On site 90 its abundance was greatest, averaging 27 stems/acre; but on sites 100 and 110 abundance averaged only 5 and 7 stems/acre, respectively. Survival of advance reproduction on high-quality sites appears limited.

The other species (Tables 1 and 2) showed no consistent pattern of abundance by site. Many of these species, which were never abundant, occurred frequently on sites 90 and 100. They occurred infrequently on site 110. These species included American chestnut, American hornbeam, ash, black cherry, blackgum, black oak, butternut, white basswood, Carolina silverbell, eastern hophornbeam, Fraser magnolia, sourwood, and white oak.

Composition of all advance reproduction of timber species only is shown by site index in Table 3. Although all stands were classified as natural yellow-poplar before thinning and were 100 percent yellow-poplar after thinning, it is apparent that future stands will have a mixture of species that might be classed as cove hardwoods.

Significant effects of site and stand density on height, basal area, and abundance of advance reproduction were sought through correlation analysis. Neither residual basal area nor number of trees, nor ratios of the same using residual/initial values as independent variables, appeared to be even moderately correlated with basal area or stem numbers of advance reproduction. Site index had only a very slight, almost negligible, effect on height of advance reproduction. Residual basal area, however, did affect height of advance reproduction rather strongly; at the lowest residual basal area advance reproduction was some 8 feet taller than at the highest.

The relationship between average height of the tallest 280 saplings/acre and their composition appears in Figure 1; saplings averaged 22.4 feet tall with a range of 10.7 to 36.8 feet. Flowering dogwood was the most abundant species, and excepting black locust and sweet birch on site 90, it was also the shortest. Yellow-poplar was the tallest species on all sites, but only slightly

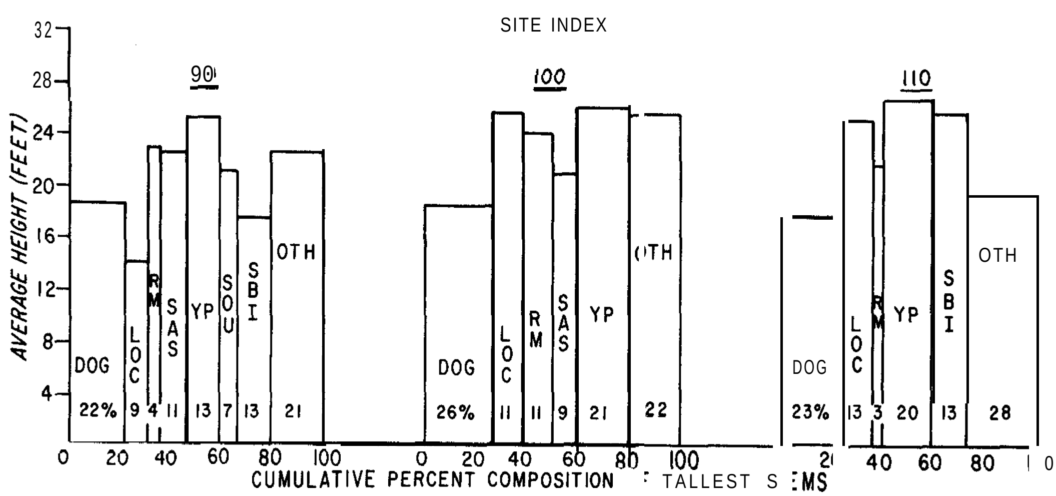

Figure 1.--Average height and composition of the tallest saplings of advance reproduction 15 years after thinning yellow-poplar stands 60 years or older in the Southern Appalachians. **Abbreviations** are: DOG flowering dogwood, LOC black locust, RM red maple, SAS sassafras, YP yellow-poplar, SOU sourwood, SBI sweet birch, OTH includes: site 90, American chestnut, northern red oak, eastern hophornbeam, ash spp., Carolina silverbell, white oak, eastern hemlock, Fraser magnolia; site 100, sourwood, sweet birch, northern red oak, eastern hophornbeam, ash spp., Carolina silverbell, white basswood, sugar maple, spice-bush; site 110, American chestnut, northern red oak, ash spp., eastern hemlock, hickory spp.

Table 3.--Composition of advance reproduction of timber trees by site in thinned even-age yellow-poplar stands 60 years or older.

Species	Site index					
	90 N-14	100 N-13	110 N=9	90 N-14	100 N-13	110 N-9
	Basal area (percent)			Number of trees (percent)		
Ash spp(Fraxinus L.)	5.0	0.4	0.2	1.9	4.3	1.0
Black cherry (Prunus serotina Ehrh.)	0.2	0.0	0.0	0.2	0.0	0.0
Black locust (Robinia pseudoacacia L.)	15.7	20.4	25.6	10.4	15.0	16.4
Black oak (Quercus velutina Lam.)	0.3	0.0	0.0	0.8	0.0	0.0
Eastern hemlock (Tsuga canadensis (L.) Carr.)	11.3	0.3	0.2	8.3	1.1	1.6
Hickory spp. (Carya Nutt.)	4.2	0.9	3.8	8.3	3.8	7.9
Northern red oak (Quercus rubra L.)	8.6	0.7	2.4	4.5	1.6	1.6
Red maple (Acer rubrum L.)	2.3	7.1	5.1	2.6	9.6	4.2
Sugar maple (Acer saccharum Marsh.)	0.0	8.6	0.0	0.0	17.6	0.0
Sweet birch (Betula lenta L.)	37.6	1.5	21.4	56.8	11.2	51.9
White basswood (Tilia heterophylla Vent.)	0.0	2.0	0.1	0.0	1.1	0.5
White oak (Quercus alba L.)	0.9	0.0	0.1	0.7	0.0	1.1
Yellow-poplar (Liriodendron tulipifera L.)	13.9	58.1	41.1	5.5	34.7	13.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

so; complete overstory release would result in its rapidly assuming greater crown dominance. Figure 1 also indicates: (1) a trend toward cove hardwoods dominated mainly by yellow-poplar, and (2) flowering dogwood was reverting to an understory species as reproduction approached pole size.

DISCUSSION

Numbers of timber-tree saplings appear to be sufficient to regenerate these plots in most instances, but there are two notable exceptions: (1) areas heavily browsed for several years after thinning, and (2) areas in which grasses and ferns developed strongly after thinning, and which were also heavily browsed. Overall, numbers of timber-tree saplings ranged from 288 to 604 stems/acre. After the harvest cut, some additional sprouts and seedlings will appear; and some mortality will occur through logging, but sprouting should replace such losses. The new reproduction should prosper because of direct insolation and a protected soil surface favorable for moisture retention and availability.

The major unanswered question is: What effect will the 73 percent component of advance reproduction in nontimber species--especially flowering dogwood--have on the timber-tree saplings? Other than for infrequent but notorious fail spots, we know that timber species on full release from the overstory will begin rapid height growth quickly (Smith 1963; Smith 1977; Sander and Clark 1971). Species such as flowering dogwood, sour-wood, spice-bush, and rosebay rhododendron will be relegated to the understory. After complete release, yellow-poplar, especially, can be expected to make rapid height and diameter growth (Williams 1976). Sweet birch is a strong competitor with yellow-poplar in this advance reproduction, as is black locust (Table 3). In time, however, both species are expected to revert to intermediates, or at best low codominants, in competition with yellow-poplar.

Any decision on treatment of advance reproduction must await the regeneration cut. In many cases, it would be unwise to eliminate most, if any, of the larger desirable saplings. Special care, however, should be taken by loggers during felling and skidding to minimize sapling damage. After logging, seriously damaged saplings should be cut to ground level to encourage resprouting. A second age class of reproduction will develop after logging, but it should not be detrimental to the sapling class now present. The younger stems will serve to reinforce development of reproduction, especially in larger openings, and will serve as trainers to aid in natural pruning of larger saplings.

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THE INFLUENCE OF DIFFERENT SITE PREPARATION METHODS ON NATURAL REGENERATION IN BOTTOMLAND STAND&

Jon T. Morrissey and Andrew W. Ezell[2/]

Abstract.--An evaluation of first-year natural regeneration of East Texas bottomland hardwoods was conducted on three ten-following site preparation treatments: shear; shear and broadcast burn; total injection; partial injection; control. Vegetation data was collected from intensive pre-harvest and first-year growing season inventories. Analysis showed a significant difference between treatments on the amount of first-year sweetgum regeneration. Also, first-year species composition differed from both the pre-harvest overstory and advance regeneration compositions. The number of desirable species. (sweetgum and oaks) and total species significantly increased from pre-harvest regeneration levels.

INTRODUCTION

High-quality hardwoods are becoming increasingly depleted. Since the early 1950's Grade 2 quality and better logs have decreased by almost fifty percent (McKnight 1966). While the availability of quality logs has decreased, there has been an increase of low value, poor-quality trees. In East Texas, eighty percent of the hardwood sawtimber is of Grade 3 quality and lower (Woessner 1971). To improve this situation, intensive silvicultural methods must be initiated. Proper artificial and natural regeneration offer possibilities for hardwood stand improvement.

Artificial regeneration may result in increased volume yield since the arrangement, composition, and the genetic quality of a stand are closely controlled (Smith 1962). The benefits are reduced due to the possibility of mistakes in choosing species and varieties that are unsuitable to the environment. The role of widespread hardwood plantations offers potential for the future but expensive and continually rising establishment costs currently override substantial resource contributions.

Natural regeneration offers a practical alternative to improve the quality of East Texas hardwoods. Hardwoods regenerate naturally through use of clearcutting, seed-tree, shelterwood and selection cutting methods. Of these, clearcutting has the greatest application for naturally regenerating southern hardwoods (Kellison, Frederick and Gardner 1981). Clearcutting initiates stump sprouting and favors seedling establishment of intolerant species. Unfortunately, clearcutting also stimulates growth of undesirable intolerant species. To reduce this competition and increase the survival probability of desirables, site preparation methods should follow clearcutting. Successful site preparation methods for natural hardwood regeneration are chop, shear and chemical injection. Roller-drum chopping, as compared to shearing, reduces slash with less environmental impact but also reduces the stump and root sprouting ability of desirable species. Shearing promotes stump sprouting and reduces residual undesirables such as vines (Kellison, Frederick and Gardner 1981). Injection reduces undesirable advance reproduction and sprouting through application of herbicides to specific unwanted individuals.

The objectives of this study were to evaluate the effects of clearcutting and different site preparation techniques on bottomland hardwood regeneration in East Texas, and to correlate pre-harvest stand species composition to post-harvest first-year hardwood regeneration.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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METHODS

The Study Area

Three ten-acre study units were established on a first-level terrace of the Neches River bottom in southeastern Tyler County, Texas. The units are located at the Forest bake Experimental Research Area, owned and operated by Temple-Eastex, Inc.

The area encompassing the three ten-acre units is approximately a seventy year old bottomland stand comprised mostly of oaks and sweetgum on the Bibb soil series. This soil series is typically a nearly level, poorly drained floodplain with acidic surface and subsurface clay soil. The area receives over 50 inches per year in precipitation in which flooding may occur. Periodic flooding is restricted to localized drains. Flooding by the Neches River has been virtually eliminated by dam construction.

Study Establishment Procedure

The study area was determined to be clearcut. Clearcutting has the widest application associated with regenerating species of intolerant nature.

The size of the clearcut units was set at lo-acres. This size probably would show the same results as larger areas and was more economically justifiable than smaller areas.

Pre-Harvest Inventory Procedure

A pre-harvest inventory of each unit was administered from May through July 1981, using fifty evenly spaced sample points on six parallel transect lines. The overstory was evaluated for species composition and basal area. The suppressed (0.0l-acre) and herbaceous (0.001-acre) layers were evaluated by using nested circular plots around each plot center. The amount of regeneration was recorded for each species present. After completion of the inventory, all trees of merchantable diameter size were marked, cut and removed by Temple-Eastex, Inc. from August through October 1981.

Site Preparation Procedure

After the completion of harvest operations, each ten-acre unit was divided into ten square (3.2 x 3.2 chains) one-acre site preparation areas. Treatments chosen were shear, shear and broadcast burn, total injection, partial injection and control. Each ten-acre unit consisted of two repetitions of the five treatments. Each treatment was randomly assigned and positioned for each repetition.

Shear vs. Shear and Burn

The designated shear, and shear and burn areas were prepared by use of a K-G blade equipped Caterpillar D-8 tractor in December 1981. Only one pass was necessary over each area. The sheared debris was left in place on both areas. Fire lanes *were* created around each shear and burn area by the blade equipped tractor. Burning was conducted in March 1982, on days suitable for debris burning.

Total vs. Partial Injection

The live stems remaining on the designated total and partial injection areas were injected by spraying Tordon 101R in frills created by the Sanavik Swedish brush axe. On total injection areas, stems greater than 4.5 feet height were injected, while stems greater than 3.0 inches d.b.h. were injected on partial injection areas. Injection was completed by March 1982.

First-year Inventory Procedure

The 0.001-acre (mil-acre) circular plots used before harvest were re-established. Data measured and tallied was first-year: species composition; origin (seedling or sprout); heights (to nearest 0.1 foot); percent canopy cover; percent ground cover. Stumps were measured and tallied for sprouting ability. Stump diameter, height, species, and number of sprouts were recorded. The inventory was conducted during the first two weeks *of* October 1982.

Analysis

Analysis of variance was used to test for significant species composition (total and desired species) changes and differences in amounts of regeneration. Each test was tested at probability levels of 0.05 and 0.01. Individual tests conducted were: 1981 pre-harvest regeneration layer; 1982 post post-harvest first-year regeneration layer: between the 1981 and the 1982 regeneration layers: 1982 site preparation treatments. Post-harvest regeneration was further tested by analysis of variance for significant differences between each site preparation treatment by height of regeneration and origin. All analysis of variance models were considered fixed.

RESULTS AND DISCUSSION

1981 Pre-Harvest Growing Season

Overstory Layer

The basal area overstory inventory suggests a dominance of commercially desirable species (oaks and sweetgum) (Table 1). Oaks and sweetgum comprised 54 percent and 24 percent, respectively *of* the mean total 70 $ft.^2$ of basal area per acre. Basal area for Blocks 1, 2, and 3 was 65, 77, and 68 $ft.^2$/A., respectively.

Table l.--Preharvest overstory species composition.

SPECIES	BLOCK		
	1	2	3
	---% of Total Basal Area----		
Water Oak	20.4	24.9	32.6
Sweetgum	18.9	19.5	33.7
Willow Oak	18.9	11.2	9.7
Cherrybark Oak	9.1	2.6	9.1
Overcup Oak	5.2	5.5	0.9
Swamp Chestnut Oak	2.1	4.9	1.8
Other Oaks	0.9	2.8	0.3
Hornbeam	7.3	4.2	1.2
Blackgum	3.7	4.7	2.6
Other Species	13.5	19.7	8.1

*Average basal area per acre.

Volume figures provided by Temple-Eastex, Inc. indicated that approximately 5500 broad feet per acre of timber was cut during the harvest operation.

Regeneration Layer

Pre-harvest regeneration mil-acre plots revealed oaks and **sweetgum** to comprise 38 percent of an average 2793 seedlings per acre (Table 2). The majority of the remaining 62 percent consisted of shade tolerant species (hornbeam, American holly, hawthorn, Red maple).

Table 2 .--Pre-harvest regeneration estimates for all research blocks.

SPECIES	BMCK		
	1	2	3
	--------# trees/A. ----------		
All Species	3740	2280	2360
Sweetgum	400	661	121
oaks	442	563	1301
Sweetgum + Oaks	842	1224	1422

1982 First-Growing Season

Blocks

The re-established regeneration plots revealed oaks and **sweetgum** to comprise 34 percent of an average of 6547 seedlings andsprouts per acre (Table 3). As in the pre-harvestinventory, the majority of the remaining 66 percent consisted of shade-tolerant species (hawthorn, hornbeam, slippery elm).

Table 3.--First-year regeneration estimates for all research blocks.

SPECIES	BLOCKS		
	1	2	3
	-----------# trees/A.-------		
All Species	6820	6300	6520
Sweetgum	1957	1682	1402
oaks	539	599	457
Sweetgum Oaks	2496	2281	1859

Site Preparation Treatments

Analysis of variance of the amount of **sweet-**gum regeneration showed a significant difference between site preparation treatments (Table 4). **Sweetgum** regeneration was 59 percent higher or partial injection areas compared to control areas and over 600 percent higher than total injection areas. Oak regeneration appeared to decrease with an increase of site preparation intensity. Control areas had over 330 percent more oaks than did shear and burn areas.

Table 4.--First-year regeneration estimates for all site preparation treatments.

SPECIES	TREATMENT				
	PARTIAL INJECT	TOTAL INJECT	**SHEAR**	SHEAR, BURN	CONTROL
	---------------# trees/A.---------------				
All Species	7855	4910	8510	4585	6875
Sweetgum	**2835***	460	2235	1100	1775
oaks	745	565	345	230	775
Sweetgum + oaks	3580	1023	2580	1330	2550

*Significant difference at probability level 0.01.

Other analysis of variance tests showed no differences between site preparation treatment of species composition, amounts of total species per acre, and individual species heights. However, species seedling or sprouting origin was analyzed and showed significant differences between site treatments. Further anlysis probably will show **sweetgum** sprouting is effected by different site preparation treatments (Table 5).

Table 5.--Origin of first-year regeneration stems.

SPECIES	SEEDLINGS	SPROUTS
	------# trees/A.---------	
Sweetgum	561	1120
oaks	366	166

1981 Vs. 1982 Regeneration

Test results for possible correlation between 1981 and 1982 regeneration were primarily obtained by analysis of variance. Average reproduction per acre was tested and found that 1982 reproduction significantly increased total species, sweetgum, and **sweetgum** plus oaks from 1981 reproduction levels (Table 6). These differences may be attributed to the sprouting ability of certain species. **Sweetgum** is inherently a more prolific sprouter than oaks. **Sweetgum** regeneration averaged 2 sprouts for each seedling, while oaks averaged 2 seedlings for each sprout. Percent change of regeneration for each site preparation treatment was formulated between both seasons (Table 7).

Table 6.--Comparison of pre-harvest and first-year stocking levels for all blocks.

SPECIES	1981	1982
	------# trees/A.------	
All Species	2793	6547"
Sweetgum	394	1681"
oaks	813	532
Sweetgum + Oaks	1207	**2213***

*Significant difference of probability level 0.01.

Table 7.--Percent change in pre-harvest and **first**-year regeneration stocking levels for all site preparation treatments.

SPECIES	TREATMENT				
	PARTIAL INJECT	TOTAL INJECT	**SHEAR**	**SHEAR, BURN**	CONTROL
	------------------%	------------------			
All Species	290	100	125	75	270
Sweetgum	750	70	270	265	280
oaks	-38	0	-50	-74	10
Sweetgum +	130	25	90	10	210

The resulting 30 percent decrease in oak reproduction may subsequently result in a mature stand of **sweetgum** instead of oak. The 1981 preharvest overstory and herbaceous inventories showed oaks to comprise 54 percent and 29 percent of total composition respectively. The 1982 inventory showed oaks to comprise only 8 percent.

SUMMARY AND CONCLUSIONS

In 1981, a mature oak-sweetgum stand was harvested after an intensive overstory, suppressed layer, and herbaceous layer inventory was administered. During the following dormant season site preparation activities were conducted. Another inventory followed the 1982 growing season. Site preparation had little significance on amounts of new regeneration, species composition, and species heights. However, **sweetgum** responded to partial injection areas 159 percent more than control areas and 600 percent more than total injection areas.

Species composition changed from an **oak-sweet**gum stand in 1981 to a **sweetgum** regeneration area in 1982. Oak declined by 30 percent from the preharvest herbaceous inventory to the first-year regeneration inventory. Oaks also progressively declined with increased site preparation intensity.

The results of this study suggest that **clear**cutting followed by light intensity site preparation will sufficiently regenerate a bottomland hardwood site in deep East Texas. It is important that the original stand have a high proportion of mature **de**sirables. Of these desirables, some must have **prolific sprouting** ability to assure early establishment and subsequent dominance.

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APPENDIX

Scientific and Common Name of Wood Species

Scientific Name	Common Name
Acer rubrum L.	Red Maple
Carpinus caroliniana Walt.	American Hornbeam
Crataegus spp.	Hawthorn
Ilex opaca Ait.	American Holly
Liquidambar styraciflua L.	Sweetgum
Nyssa sylvatica Marsh.	Blackgum
Quercus falcata vah. *pagodaefolia* Ell.	Cherrybark oak
Quercus lyrata Walt.	Overcup Oak
Quercus michauxii Nutt.	Swamp Chestnut Oak
Quercus nigra L.	Water Oak
Quercus phellos L.	Willow oak

1/ Names bases on Little, Elbert L., 1980, The Audubon Society Field Guide to North America Trees.

WATER OAK REGENERATION IN THE SOUTH'S UPLAND BOTTOMLAND[1/]

John C. Adams[2/]

Abstract.--Water oak (Quercus nigra L.) is an important component of the small bottoms and hardwood producing stands located in areas classified as pine types. The species is highly variable and in natural stands produces excellent timber. Plantation establishment has not proven as successful as expected primarily because of a problem with dieback and slow growth in the two years following planting. The result of this problem will be a continuation of the use of natural reproduction to reestablish stands, or the use of other oak species which apparently suffer less from the dieback problem.

INTRODUCTION

Water oak (Quercus nigra L.) occupies a very large range across the south from the coastal areas to the foothills of the mountains. The species occurs on a variety of sites but makes its best development on well drained moist soils. Genetically the species is very diverse and a number of hybrids have been recognized (Ingens-Moller 1955, Fowells 1965). Phenotypically the species is quite plastic in response to the environment in which it exists.

Water oak is in the red oak group but is generally not considered one of the select red oaks as is cherrybark (Q. falcata var. pagodaefolia Ell.) and Shumard (Q. shumarciii Buck L.) (Kingsley and Powell 1979). However, water oak is an important species and is used for a variety of products across its range. It is a component of several bottomland types and widespread in the smaller stream bottoms and waterways located in the lower south.

It is these smaller waterways, intermittent streams, and flats located throughout the pine hill country of the Gulf coastal plain that this paper references as upland-bottomlands. These are not in the major river bottoms but are hardwood producing areas found in what'is generally considered pine land. In this area water oak contributes heavily to the hardwood resource.

Since water oak is a viable component of these forested areas, and in certain of these a major component, the species needs attention if we are to improve the individual stands and make them productive after years of absence of management.

IMPROVEMENT OF THE WATER OAK COMPONENT

In 1976-77 two projects were initiated at Louisiana Tech University. One was genetic improvement of water and willow oak and the other was silviculture improvement of bottomland hardwoods. The genetic project was designed to investigate the diversity within water oak and develop materials that could be used in plantation establishment. The second project was to determine methods of establishing hardwood plantations in the small upland bottoms. The following is a summation of observations made during the past five years of working with water oak.

Seedling Production. Nursery production of water oak is relatively simple and suitable seedlings can be grown in one season. Seedling spacing in the nursery beds has been 8-16 feet per square foot with the higher number producing the

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta,GA, November 3-5,1982.

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best plantable seedlings from a size (handling) and root/shoot ratio standpoint. An additional year in the nursery beds (2-O seedlings) results in seedlings that are greatly out of root/shoot balance and extremely difficult to handle in plantation establishment.

One problem noted with large scale nursery production is the inability of the collection crews to collect only water oak acorns. In a representative nursery bed water oak, willow oak, laurel oak and hybrids of two of the above can be found. This is a problem because the water oak is a higher quality species than laurel and some of the hybrid material. Poor performance from planting mixtures of these species giveswater oak a bad reputation from a quality standpoint. Similar seed morphology of these species causes this problem and probably the best way to avoid these mixtures is correct identification of the parent trees by seed collection crews.

An alternative to the bare rooted seedlings is containerization. Considerable interest in this technique has been expressed and the use of these containerized seedlings may prove advantageous. Elam et al (1982) has shown that water oak can be grown in containers and successfully out planted. Containerized seedlings research at Louisiana Tech has shown that healthy water oaks can be grown in a variety of containers but the size of the seedlings (generally less than 10 inches) severely limits their use without intensive cultivation following planting. Size limitation recommendations for quality hardwood bare-root seedlings of 30-36 inches in height and 1/4 - 3/8 inches root collar diameter (McKnight and Johnson 1980, Weber 1972) may be offset in containers by minimizing the disturbance to the root system.

Plantation Establishment. Several small plantations have been established to obtain a better understanding of problems associated with planting water oak and related species in these small hardwood bottoms. In each plantation the site was well prepared by discing and care was taken to handle the seedlings for maximum survival. Seedlings were either grown in the Louisiana Office of Forestry nursery or the Louisiana Tech University nursery. One planting was with 2-O seedlings and the others were with 1-O seedlings. In each planting only healthy seedlings were used and care was given to plant seedling properly,

The first problem encountered was with the 2-O seedlings. They were too large for efficient handling (average height approximately five feet) and resulted in difficulty in planting. Shortly after planting in February strong winds caused many of the larger seedlings to bend over and they never recovered. The top was too heavy for recovery. Consequently the seedlings either died or sprouted from below. Smaller seedlings (approximately 3 feet in height) did not show this problem with wind damage.

The second and most severe problem is the dieback phenomenon associated with newly planted seedlings. In each planting over a three-year period using genotypically different seedlings from two nurseries, the pattern of dieback and reflushing of leaves was present.

Three different dieback patterns were noted.

1. Normal leaf flush starts, then all new development dies. Sprouting then comes from the stem or the root collar of the seedling. The seedling above the secondary flush is dead.

2. No leaf flush starts and seedlings appear dead. Leaf flush starts as much as 40 days after water oak in the area has flushed and the flush is from the stem.

3. No leaf flush starts and seedlings appear dead. Leaf flush may be delayed until mid-summer and flushing comes from the root collar or below.

Where dieback occurred and flushing was from the stem, leaves were small and appear to be much less vigosous than those from the root collar area. The effect of this dieback is to negate the production of large, strong seedlings in the nurseries.

In one plantation in which water oak, cherrybark, Shumard and Nuttall (Q. nuttallii Palmer) are represented, only the water oak shows this dieback characteristic in significant amounts. This indicates that water oak may be more sensitive to bare-root transplanting than are the other oaks.

There are two possibilities for improvement of this dieback problem. One is to avoid seedlings that are too large (greater than 36 inches). The larger seedlings result in a root/shoot ratio that is apparently out of balance which causes problems for the newly established seedlings. The second possible improvement is to lift the seedlings during the hard winter months. Seedlings lifted toward the end of the planting season show more transplant shock then those lifted earlier. Water oak seedlings in nursery beds retain their leaves throughout the winter. The possibility exist for these seedlings to start metabolic activities related to growth when warm days occur during the winter. If lifted at this time, there may be more transplant problems.

ALTERNATIVES TO PLANTATIONS

Generally plantation establishment in small bottoms has had low priority for both the private individual and industrial landowner. Pine is the predominant tree crop with high value and low management cost. Most research indicates that successful hardwood plantation establishment requires intensive site preparation (Hunt 1976, Kennedy 1980). This requires considerable investment *in* preparation before planting and in cultivation for one to three years after planting. In the areas where pine is king from a value standpoint, there has been little incentive for the landowner (large or small) to invest in their hardwood holdings. Only in the major river bottoms where hardwoods predominant is this plantation cost considered cost effective.

The difficulty of establishing water oak plantations, expense in maintaining plantations, and low stumpage prices leaves the probability of widespread interest of this species and other hardwoods in these small bottoms in doubt. However, *these* bottoms will continue to supporthardwoodand land managers can use sound silvicultural techniques to establish and maintain productive natural stands. Natural stands will not be pure water oak, sweetgum, or cherrybark but a mixture from which the best trees will eventually reach rotation age.

From a productivity standpoint one silvicultural system is most practical. This is clearcutting in small patches (< 80 acres). Most of the hardwood stands have been mismanaged both in private and industrial ownership. This mismanagement is the result of low prices and a lack of knowledge of the hardwood resource by the foresters on the ground, most of whom have been trained in and work with pine. The results are stands that are mix-species and evenage or close to evenage with a high percentage of cull or poor quality stems. The simpliest method to handle these stands is the clearcut and natural reproduction (primarily rootsprouts). A marginal low productivity forest is eliminated and a new dynamic evenage, mixed species hardwood forest will emerge. This forest will be much simplier to handle from a silvicultural standpoint and in the long run more productive because of the simplicity.

Until problems associated with plantation establishment of water oak or other hardwood species are solved, most of the small bottoms will be reproduced naturally. Poterfield et al (1977) in their economic analysis of hardwood plantations and natural stands also indicated no foreseeable widespread move in the direction of plantations in the management of hardwood stands.

CONCLUSION

Planting of water oak plantations in the small bottoms of the lower mid-South does not look promising. Economic considerations of site preparation, planting, and cultivation for water oak and other hardwood are difficult to justify with today's market prices for stumpage. Also water oak apparently has physiological problems in movement from nursery beds to the field which results in poor initial performance and makes the use of this species in plantations highly unlikely until some of the planting problems can be solved. Until methods and techniques are developed to solve these problems, natural reproduction following a clearcut will probably be the most effective method to regenerate these hardwood stand. Water oak will be a component of these stands but not necessary the predominant species. Sound low cost silvicultural techniques can greatly increase the productivity of stands resulting from poor or no management in the past.

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FIRST-YEAR GROWTH OF ETIOLATED NORTHERN RED OAK[1/]

G. M. Hopper, D. Wm. Smith, and D. J. Parrish[2/]

Abstract.--Rapid height growth in northern red oak (Quercus rubra L.) seedlings may be an important factor in the early establishment of plantation culture. Red oaks grow very slowly during the formative years and any cultural practice that would stimulate height growth and stem elongation rates would benefit artificial regeneration of oaks, provided such treatments do not impair survival and subsequent seedling growth. Northern red oak and bear oak (Quercus ilicifolia Wangenh.) acorns were germinated and then grown in the dark at 25/15°C (16/8 hr.). The etiolated seedlings were then moved to 60% sunlight in a greenhouse for four weeks so that leaf expansion and stem lignification would stabilize the seedling. Dark-grown seedlings were taller than light-grown plants. Survival data and one season growth data after outplanting was collected on etiolated northern red oak seedlings and compared to typical 1-O and 2-O nursery stock.

INTRODUCTION

Interplanting of northern red oak, a valuable timber species, may improve stand composition and increase stocking levels, on sites where natural red oak regeneration is low. However, early seedling growth is slow and seedlings do not compete well with herbaceous and more intolerant woody species (Olson and Hooper, 1972; Russell, 1972; Wendle, 1980). Various treatments have been tried to increase growth of transplanted seedlings: mulching, cultivation, herbicides, top pruning, fertilization and use of older seedlings, all have failed. However, seedling size at planting was found to correlate positively with subsequent seedling growth in northern red oak in plantation culture (Wendle, 1980). Wendle, therefore, recommended larger "super seedlings" be used for outplanting.

Northern red oak seedlings that have been grown for a brief period in the dark respond with enhanced shoot elongation, etiolation, and thus produce taller seedlings. This dark treatment may prove useful for more rapid growth of red oak from seed. Such a conditioning might permit fall collected seeds to be outplanted as seedlings the following spring, thus eliminating at least one year of nursery growth and reducing costs.

Etiolation occurs whenever a plant grows without light. Depletion of the plant's metabolic reserves results in a decrease in total plant dry weight. Etiolated stems are notably taller and thinner than light-grown stems. This photomorphogenetic response is due to internal mechanisms within the plant. Etiolation is commonly used in seed testing. Differences in growth during the etiolated elongation of shoots can be used to distinguish various seedlot genotypes or treatment effects. When etiolated growth was used for testing on northern red oak in a previous study, we observed great increases in shoot lengths. Subsequently, it was observed that leaf development following such a dark treatment was normal and that stem thickening occurred rapidly near the base of the shoot once' light was restored and photosynthesis was begun. Based on these observations, an experiment was designed to 1) evaluate etiolation as a method to increase early height growth in northern red oak and thereby produce larger planting stock for field planting in a short period of time; and 2) compare growth and development parameters of one-year etiolated seedlings with normal nursery stock.

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METHODS AND MATERIALS

Seed Collection, Handling and Germination

Acorns were collected from the ground under the canopies of nine northern red oaks (Quercus rubra L.) in Blacksburg, Virginia (elevation 700m) between 22 and 27 October 1981. The acorns were then submerged briefly to float off trash and bad seeds. Moisture content was determined gravimetrically from three samples of five acorns 'each. The samples were weighed fresh and then oven dried at 105°C for 24 hours. Moisture content at collection was 64% (oven dry weight basis). Seeds were soaked (imbibed) for 52 hours during which the moisture content was increased to 70%. All acorns were placed in trays on moist vermiculite/ peat potting medium, covered with wet paper towels and stratified at 5°C. After 16 weeks of stratification, acorns were germinated in place on the trays in a darkened growth chamber at 25/15°C (16/18 hours thermoperiod). Germination after 28 days was more than 90% and germination rates were good (90% in 10 days). A seed was considered germinated once the emerged radicle showed positive geotropism.

Etiolated Growth and Early Conditioning

Germinated acorns (1 to 2 days old) were planted In one liter plastic pots in a vermiculite/ peat potting medium. The pots were placed in a grwth chamber at 25/15°C, 16/8 hours in total darkness. Seedlings were grown for four weeks. Simultaneously, germinated acorns were planted in pots in potting medium and grown for 4 weeks in a greenhouse (light treatment). Growth measurements were taken from both dark-grown and light-grown northern red oak seedlings after the initial 4 weeks growth period. The etiolated seedlings were transfered to the greenhouse under 60% shade (obtained with fiber glass shade cloth) for 3 weeks. To complete full-light adaptation conditioning, seedlings were then transfered to full sunlight for another 3 weeks.

Bear Oak Study

In a corollary species trial, bear oak (Quercus ilicifolia Wangenh.) seeds from southwest Virginia were stratified for 12 weeks and germinated as previously described for northern red oak. Germinated acorns were planted in root trainers in the greenhouse under 60% shade. One-half the seedlings were totally enclosed in cardboard boxes for 6 weeks (dark treatment). After 6 weeks, the boxes were removed. Growth measurements were then taken on both light-grown and dark-grown bear oak seedlings.

Outplanting of Northern Red Oak

On 5 May 1982, forty light conditioned, etiolated,northern red oak seedlings were planted at 25 x 25 cm spacing in a fertilized (Osmocote 10-16-8, +Fe) nursery bed at Critz, Virginia. Seedlings were hand planted in an effort to keep the root system intact. Also, 50 stratified and pregerminated acorns from the same seedlot were planted at a similar density in the same nursery bed. Etiolated seedlings were staked. Except for irrigation, no further treatments were imposed on the seedlings.

Lifting

All seedlings were lifted by hand on 12 October 1982. The seedlings were brought to the lab, cleaned and measured. Shoot lengths, root lengths, root collar diameters, shoot and root dry weights (oven dried at 60°C, 52 hours), number of leaves, and number of flushes (as indicated by bud scale scars) were measured on each seedling.

RESULTS AND DISCUSSION

There was some initial concern about the survival and establishment potential of the etiolated seedlings, because of the spindly nature and top heaviness of the etiolated structure. To the contrary, the results showed that better than 90% survival was recorded on the etiolated plants after the first growing season. Although the nursery bed competition was probably not as severe as average field competition, the nursery was not weeded or treated for competition in any way. Oaks in general are very hardy; and, with proper handling, survival in artificial regeneration systems should not pose a problem.

Etiolated seedlings of northern red oak and bear oak were taller than light-grown plants (fig. 1). Both species behaved similarly, although bear oak is a small seeded red oak species, and northern red oak is a large seeded species. Height growth in the dark was more than twofold greater in bear oak and nearly two and a half fold greater in northern red oak. If the taller seedlings stay taller and grow faster, this effect might benefit production of large container stock. Outplanting larger seedlings has been reported to provide some advantage in future seedling growth (Wendle, 1980).

Differences in growth after one season in a nursery bed between etiolated seedlings and seedlings produced from spring sown seeds were compared (Table 1). Etiolated seedlings were larger in almost every growth parameter measured. They were taller, had larger root systems and were thicker at the root collar than normal seedlings.

The production of more vigorous planting stock might be beneficial by Increasing the early grwth and establishment of red oaks. Farmer

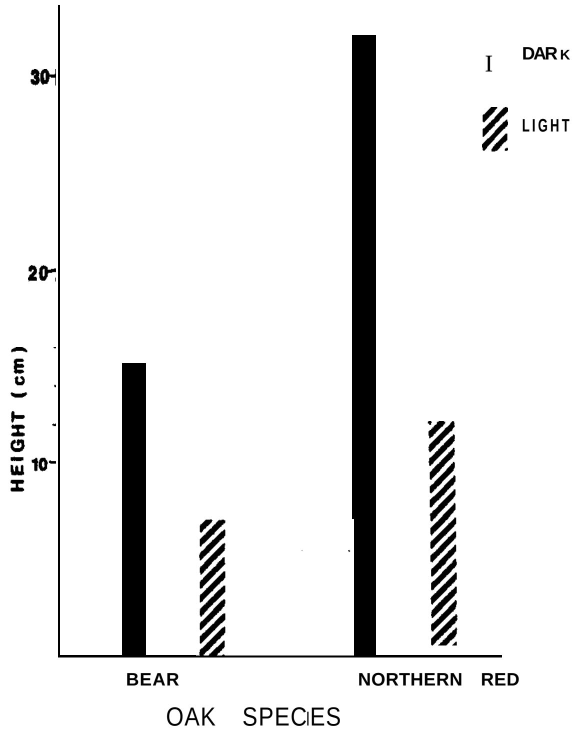

Figure 1.--Growth differences in bear oak and northern red oak seedlings after four (red oak) or six (bear oak) weeks of growth in the dark or light.

(1975) suggested that increasing the juvenile shoot growth in red oaks would increase leaf area and thus produce larger root systems and more vigorous seedlings. Although the number of leaves appeared to be greater for normal seedlings, this was due to increased branching in normal seedlinns. Etiolated seedlings tended to-have one unbranched stem.

The mean growth of etiolated seedlings would have been greater if all the etiolated seedlings had continued to grow after planting. However, only 46% of the etiolated seedlings continued growth after planting, while the other 54% of the outplanted seedlings appeared to set dormant buds. Farmer (1975) reported that the variability in bud set and bud break was hormonally and genetically controlled in northern red oak.

Comparisons of differences within the etiolated seedlings are given in Table 2. There were significant growth differences between the seedlings that did not increase in height growth after planting and those plants that had multiple growth flushes. The number of leaves for the growing etiolated plants was 25 versus only 3 for the non-growing seedlings, and may represent a vital statistic in increasing the production of large seedlings. Height growth means for growing plants were nearly twofold larger (61.6 to 34.5 cm) than non-growing seedlings and more than two times greater (61.6 to 27.9) than normal seedlings. Similarly, root collar diameters were larger for growing etiolated seedlings with 10 mm versus only 7.6 mm in non-growing etiolated plants and 6.3 mm in normal seedlings. Dry weight data show that seedlings that were etiolated were heavier, thus producing more biomass with more than half the

Table 1.--Vital growth parameters at end of one season for etiolated northern red oak seedlings (n = 35) versus normal spring sown seedlings (n = 35) of similar seed origin.

Growth Parameter	Etiolated Seedlings	Normal Seedlings
Heights (cm)	46.5a[1/]	27.9b
Root length (cm)	29.0a	25.7b
Root collar diameter (mm)	8.8a	6.3b
Total dry weight (gms)	14.7a	8.7b
Root dry weight (gms)	9.5a	6.6b
Shoot dry weight (gms)	5.2a	2.0b
Number leaves	13.7a	18.6a
Number flushes	2.6a	2.8a
Root/Shoot ratio (gms/gms)	2.1b	3.4a

1/ Means in a line not followed by the same letter are significantly different ($p < .05$) as determined by the Duncan's New Multiple Range Test.

Table 2.--Comparison within the etiolated treated northern red oak seedlings between those seedlings that did not grow after planting and those seedlings that grew considerably after planting during the first year.

Growth Variable	All Seedlings	Seedlings With Minimal Growth (n=19)	Seedlings With Growth (n=16)
Height (cm)	46.5b[1/]	34.5c	61.6a
Root length (cm)	29.0a	30.0a	28.1a
Root collar diameter (mm)	8.8b	7.6c	10.0a
Total dry weight (gms)	14.7b	7.7c	23.8a
Root dry weight (gms)	9.5b	5.4c	14.8a
Shoot dry weight (gms)	5.2b	2.3c	9.0a
Number leaves	13.7b	3.2c	25.1a
Number flushes	2.6b	1.4c	4.2a
Root/Shoot (gms/gms)	2.1ab	2.3a	1.8b

[1/] Means in a line not followed by the same letter are significantly different ($p<.05$) as determined by the Duncan's New Multiple Range Test.

weight invested in root growth. Large root systems have been reported to be a vital requisite for good oak growth in the field (Farmer, 1975; Sander, 1971). These variations within the etiolated seedling population are probably associated with a genetic component, since the seedlings were produced from a mixed seed lot.

Further comparisons were made among northern red oak nursery stock from a Virginia nursery, two West Virginia nurseries, a Pennsylvania nursery and etiolated seedlings in this study (Table 3). The etiolated treatment produced taller stems, and larger root collar diameters than nursery grown seedlings of similar climate. Even seedlings

Table 3.--Comparisons of etiolated seedling root collar diameter, heights, and root lengths with nursery stock from two West Virginia nurseries (two years data), Virginia and Pennsylvania nurseries.

Source	Age	TRT	Root Collar Diameter	Height	Root Length
	(year)		(mm)	(cm)	(cm)
Va. Reynolds, 1982	1-0	etiolated	8.8	46	29
Va. Reynolds, 1982	1-0	spring sown	6.2	27	25
W. Va. Parsons, 1982	1-0	fall sown	5.1	23	21
W. Va. Clements, 1972	1-0	fall sown	5.1	19	21
W. Va. Parsons, 1972	1-0	fall sown	8.0	23	23
W. Va. Clements, 1971	2-0	fall sown	4.3	21	21
W. Va. Parsons, 1971	2-0	fall sown	4.3	21	28
Pennsylvania, 1981	2-0	fall sown	---	27	--

[1/] W. Va. nursery data were provided by David McCurdy, Nursery Superintendent, Parsons, WV and represent averages of two to four nursery beds.

with two years of nursery growth (2-O) were not as large as the etiolated plants. common nursery stock from these systems produce healthy seedlings; however, the proposed etiolation treatment can improve the size and quality of the seedlings. More importantly, the etiolated method will allow for production of a plantable oak seedling in less than one year, thus eliminating the nursery coats and one or two years delay prior to planting.

CONCLUSIONS

Etiolation may be a feasible alternative to costly chemical treatments, herbicide control, large container systems, mulching, and fertilization now being tested for increasing height growth in oaks. The effects from etiolation on seedling growth are substantial and this process appears to be beneficial to the overall quality of the seedling.

The finer details of the technique may still be improved upon and the overall growth potential is probably greater than reported in this paper. A schematic of the proposed etiolation method is given in Figure 2. Etiolation

Figure 2.--Schematic of proposed method for use of etiolation as early height growth stimulus for northern red oak seedlings.

Proposed Date	Operation
early- to mid-October	collect acorns
15 October to 1 January	stratify acorns
1 January to 1 February	plant germinated acorns in container, in dark
1 February to 1 April	remove etiolated seedlings to partial shade for light adaption period
early April to early May	outplant

side effects do not appear to impair survival of subsequent growth. The conservative shoot growth normally associated with the juvenile stage of northern red oak must be improved in order to produce large leaf surface areas for root production and faster growth rates once field planted. This low investment treatment may be worthwhile if the "super seedlings" maintain vigorous growth and height advantage as previously reported.

Although untested on other genera and species, this method may be a viable solution for increasing height growth in many other large seeded tree species with slow early growth such as walnuts, tupeloes, and other oaks.

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RESPONSE OF UNDERPLANTED SEEDLINGS TO CANOPY

REMOVAL IN UPPER PIEDMONT HARDWOOD STANDS

T.J. Tworkoski, D.Wm. Smith, and D.J. Parrish

Abstract.--Three levels of canopy removal (90, 70, and 0% residual canopy cover) were performed to determine the effect of clearcutting and shelterwood harvesting on survival and growth of 3- and 4-year-old underplanted seedlings of white oak (Quercus alba L.), northern red oak (Q. rubra L.), and eastern white pine (Pinus strobus L.). In the second year following harvest, height growth of red oak averaged 21.2 cm in the clearcut and less than 4 cm under 70 or 90% shade. Similarly, second year white oak height growth was 10.3 cm under 0% shade but less than 4 cm under the shelterwood or no-cut treatments. Over a two year period, white pine grew taller than either oak species under all harvest treatments. In the second year following harvest, white pine in the cut stands averaged 19 cm height growth while those in uncut stands averaged 10 cm. These results indicate that these underplanted seedlings can survive and are potentially competitive with other vegetation following canopy removal.

INTRODUCTION

As a result of improper management, the typical southern upland hardwood stand is dominated by low quality trees and inferior species (Kellison et al. 1980). Soem commercially valuable oak (Quercus) species are difficult to reestablish due to insufficient advance regeneration prior to harvest (Carve11 and Tryon 1961) and because of slow growth following canopy removal (Trimble 1974). Planting in the understory (underplanting) may help alleviate some of these problems. First, sufficient numbers of oak regenerants can be ensured by underplanting several years prior to harvest. Second, it is possible that several years in the understory may permit oak seedlings to become established and to develop a root/shoot ratio that is conducive to rapid growth upon canopy removal. Third, underplanting may eliminate the need for complete site preparation and reduce the needs for postharvest cultural practices that are necessary for successful establishment of hardwood plantations (Brenneman 1980).

This study was concerned with growth of underplanted seedlings following various levels of canopy removal. The objective was to examine the effect of canopy removal on shoot growth of underplanted northern red oak (Quercus rubra L.), white oak (Q. alba L.), and eastern white pine (Pinus strobus L.) seedlings during the first two growing seasons after canopy removal. These three species occupy similar ecological niches (Fowells 1965). In addition, underplanting of white pine on poor hardwood stands has been found to be successful (Wendel 1971).

MATERIALS AND METHODS

This study was conducted at the Virginia Polytechnic Institute and State University Reynolds Pomestead Research Center near Critz, Virginia. Red oak, white oak, and white pine seedlings had been planted in 1977 and 1978 under a mixed hardwood canopy. Twelve plots, randomly scattered across intervening slopes between two major ridges were selected. Stand composition included yellow-poplar (Liriodendron tulipifera L.), maples (Acer spp.), oaks (Quercus spp.), beech (Fagus grandifolia Ehrh.), and Virginia pine (Pinus virginiana L.). The

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understory was composed of small hardwood reproduction and honeysuckle (Lonicera japonica L.) Madison fine sandy loam (Typic Hapludult) and Louisa loam (Ruptic-Ultic Dystrochrept) were the two major soils on these slopes.

In the winter of 1980-81, each plot received one of three levels of canopy removal: (1) none; (2) moderate; and (3) cleat-felling. These levels of canopy removal resulted, respectively, in 90, 70, and 0% canopy cover during the growing season as measured by a spherical densiometer (Lemmon 1956). Treatments consisted of the three levels of canopy removal and the three species in an unbalanced and nested design. Heights of underplanted seedlings were measured on 1 April, 1 July, and 1 October during 1981 and 1982. Diameters (3 cm above the root collar) were measured on 1 October of each year. Differences at the .05 alpha level were considered significant, and means were separated by Harvey's procedure (Harvey 1975).

RESULTS

Height and Diameter Growth Comparisons Within Canopy Treatments

Height growth of white pine was consistently greater than red or white oak across all treatments (Table 1). Red and white oak did not differ significantly in height growth during either season. In the no-cut treatment (90% shade) , white pine grew significantly taller over the two year period than red or white oak (18.7 cm for white pine vs. 0.8 and 4.5 cm for red and white oak, respectively). Under full canopy, oaks grew less in 1982 than in 1981 whereas white pine showed no difference between years. Red oak height increment was negative during 1982, reflecting a stem die-back that frequently occurs in oak (Tworkoski 1982).

Height growth of white pine was also greater than oak under 70% shade (Table 1). Height increments of white oak did not differ significantly from those of red oak. However, unlike the no-cut treatment, there were no differences in height growth for oaks 'across years (approximately 3 cm both years). The 1982 white pine growth two years after partial canopy removal was more than twice the 1981 increment.

Yearly height growth in the clearcut (0% shade) treatment differed from the partial and full shade treatments (Table 1). Oak, as well as white pine height growth was greater in 1982 than 1981. The two year total height growth of white pine was not significantly greater than red oak (24.1 cm vs. 22.4 cm, respectively). Two year height growth of white oak (11.9 cm) was significantly less than red oak and white pine.

Table 1. Mean height growth of underplanted white oak, northern red oak, and white pine seedlings in canopy removal treatment areas in Patrick County, VA.

Measurment Period	RO 1/	WO	WP
	---Height	Increment	(cm)--
	NO	CANOPY	REMOVAL
1981	3.0 b 2/	3.3 b	9.5 a
1982	-2.2 b	1.2 ab	9.2 a
Two Year Total	0.8 b	4.5 b	18.7 a
	PARTIAL	CANOPY	REMOVAL
1981	2.9 a	3.2 a	6.4 a
1982	4.2 b	2.7 b	16.7 a
Two Year Total	7.1 b	5.9 b	23.1 a
	COMPLETE	CANOPY	REMOVAL
1981	1.2 a	0.6 a	3.4 a
1982	21.2 a	10.3 a	20.7 a
Two Year Total	22.4.a	11.9 b	24.1 a

1/ RO=red oak, WO=white oak, WP=white pine.
2/ Within each row, means followed by the same letter are not significantly different at alpha level .05 (Harvey's Procedure).

Species comparisons indicate that diameter growth trends did not parallel height growth trends (Table 2). Diameter growth in 1982 of all species was greater than 1981 growth. Although white pine diameter growth was consistently greater than that of oak, the difference was not statistically detectable as frequently as were height growth differences.

Table 2. Mean diameter growth of underplanted white oak. northern red oak, and white pine seedlings in canopy removal treatment areas in Patrick County, VA.

Measurment Period	RO 1/	WO	WP
	---Diameter	Increment	(mm)--
	NO	CANOPY	REMOVAL
1981	-0.2 a 2/	-0.2 a	0.3 a
1982	0.6 b	0.5 b	2.4 a
Two Year Total	0.4 b	0.3 b	2.7 a
	PARTIAL	CANOPY	REMOVAL
1981	0.3 a	-0.3 a	0.0 a
1982	2.3 ab	0.8 b	4.0 a
Two Year Total	2.6 a	0.5 b	4.0 a
	COMPLETE	CANOPY	REMOVAL
1981	0.8 a	-0.7 b	-0.8 b
1982	5.0 b	3.0 b	9.1 a
Two Year Total	5.8 a	2.3 b	a.3 a

1/RO=red oak, WO=white oak, WP=white pine.
2/Within each row, means followed by the same letter are not significantly different at alpha Level .05 (Harvey's Procedure).

In the no canopy removal treatment, diameter growth of white pine (2.7 mm) was significantly greater than that of oak (approximately 0.5 mm). In partial shade, diameter growth of white pine (4.0 mm) and red oak (2.6 mm) were significantly greater than white oak (0.5 mm). This difference is attributable to 1982 growth since 1981 growth for all three species was was close to zero. Diameter growth of the three species with complete canopy removal was greater and followed the same trend as seedlings growing under partial canopy removal. Diameter increment of white pine (8.3 mm) and red oak (5.8 mm) were significantly greater than white oak (2.3 mm).

Height and Diameter Growth of Individual Species: Canopy Treatment Effects

Regardless of species, two year height growth was greatest under 0% shade and least under 90% shade (Table 3). This ranking of treatment effects was primarily due to 1982 growth. During 1981 the ranking of treatment effects was reversed for red oak and white pine; i.e. growth under 90% shade was greater than 70% shade growth, while 0% shade growth was least.

Table 3. Mean height growth of each species within each canopy removal treatment area in Patrick County, VA.

Measurment Period	NC[1/]	PC	CC
	---Height	Increment	(cm)--
		WHITE OAK	
1981	3.3 a[2/]	3.2 a	3.4 a
1982	1.2 a	2.7 a	10.3 a
Two Year Total	4.5 a	5.9 a	13.7 a
		RED OAK	
1981	3.0 a	2.9 a	1.2 a
1982	-2.2 b	4.2 b	21.2 a
Two Year Total	1.8 b	7.1 b	22.4 a
		WHITE PINE	
1981	9.5 a	6.4 ab	3.4 b
1982	9.2 b	16.7 ab	20.7 a
Two Year Total	18.7 a	23.1 a	24.1 a

1/ NC=no canopy removal; PC=partial canopy removal; CC= complete canopy removal.
2/ Within each row, means followed by the same letter are not significantly different at alpha level .05 (Harvey's Procedure).

White oak height increment was approximately 3 cm during 1981 across all canopy removal treatments. In 1982, height growth of white oak under 0% shade was more than four times that of white oak grown under any shade. However, due to high variability, the two-year total of white oak height growth did not differ significantly among canopy removal treatments.

Height growth of red oak under 0% shade during 1982 was more than five times that of red oak grown under any shade. The increase in white pine height growth due to clearfelling was not as dramatic as in the oaks (Two-year totals: 24.1 cm under 0% shade, 23.1 cm under 70% shade, and 18.7 cm under 90% shade).

Diameter growth during 1982 and the two-year total was greater with increased canopy removal for all species (Table 4). White oak displayed a two year net diameter increase of 2.2 mm in clearfelled and 0.4 mm in partially or no-felled areas. Diameter growth of red oak was low on 90% shaded areas and significantly increased as canopy removal increased (Two-year totals of 0.4, 2.6, and 5.8 mm for no cut, partial cut, and complete cut, respectively). During 1981, white pine displayed a net diameter loss in the clearfelled treatment. However, 1982 diameter growth was so large that two-year total diameter growth was significantly greater in the clearfelled area than in the other treatments (2.7, 4.0, and 8.3 mm for no, partial, and complete canopy removal, respectively),

Table 4. Mean diameter growth of each species within each canopy removal treatment area in Patrick County, VA.

Measurment Period	NC[1/]	PC	CC
	---Diameter	Increment	(mm)--
		WHITE OAK	
1981	-0.2 a[2/]	-0.3 ab	-0.8 b
1982	0.5 b	0.8 ab	3.0 a
Two Year Total	0.3 a	0.5 a	2.2 a
		RED OAK	
1981	-0.2 b	0.3 ab	0.8 a
1982	0.6 b	2.3 a	5.0 a
Two Year Total	0.4 b	2.6 a	5.8 a
		WHITE PINE	
1981	0.3 a	0.0 a	-0.8 a
1982	2.4 b	4.0 ab	9.1 a
Two Year Total	2.7 b	4.0 b	8.3 a

1/ NC=no canopy removal; PC=partial canopy removal; CC= complete canopy removal.
2/ Within each row, means followed by the same letter arc not significantly different at alpha level .05 (Harvey's Procedure).

DISCUSSION

Species comparisons under the no canopy removal treatment indicate that white pine competes more effectively for, or more efficiently utilizes, limited available resources than red or white oak. Under full shade the annual rate of white pine height growth remained constant during this study, indicating it is more shade tolerant than the oaks examined. In addition, the two year total of white pine diameter growth was eight times that of either oak species. However, the lower diameter and height growth of the oaks may be accompanied by an increased root system. Assimilated carbon may be shunted to the root system, resulting in a root/shoot ratio suitable for growth, should an environmental change take place (e.g. development of a gap in the canopy due to tree harvest or blowdown). The shoot dieback observed in red oak during 1982 may reflect an "attempt" by a seedling to maintain such a root/shoot ratio.

In the partial and complete canopy removal treatments, white pine growth in 1982 was greater than that in 1981. The low amount of 1981 growth was accompanied by a 20% reduction in survival resulting from attack by white pine weevil (Pissodes strobi Peck.). No further attacks were observed in 1982 when white pine exhibited large amounts of height and diameter growth. Apparently, white pine became physiologically adapted to the new environmental conditions resulting from canopy removal.

Both oak species increased height growth during the 1982 season with increased canopy removal. Because oak shoot growth is strongly dependent on elongation of preformed shoots after a period of rest (fixed growth) (Kozlowski 1964), it is likely that 1981 growth was strongly dependent on environmental conditions at the time it was formed. Thus, in canopy removal treatments, 1981 oak growth probably reflected preformed shoots initiated under a canopy in 1980 while 1982 growth was initiated in 1981 under moderate or no shade conditions. In 1982, growth in clearfelled areas was greater than in partially-felled areas, which in turn was greater than no-felled areas; the reverse of 1981 trends. It appears that oaks underplanted several years prior to canopy removal can grow quickly soon after release. However, it is important to monitor future growth to determine if the rapid growth continues, and to evaluate how they compete with other vegetation.

CONCLUSIONS

The results show that red and white oak seedlings can be planted under a full canopy. In the second year after harvest, oak seedlings grew rapidly, suggesting that underplanted oaks are established and competitive with surrounding vegetation. Regeneration of red and white oak appears viable using a combination of underplanting and shelterwood cutting or clearfelling. Future progress of these seedlings should be monitored to determine the longevity of the rapid growth and the ability of underplanted seedlings to be a significant component of future stands. Additional research is necessary to establish the most suitable timing of canopy removal. If root systems of underplanted oaks continue to enlarge while in the understory, then a delay in canopy removal may be desirable.

As the amount of canopy removal increased, white pine was more severely attacked by white pine weevil during the first year after canopy removal. In addition, white pine grew more slowly in clearcuts than in shade. It seems likely that, at that time, the pine was physiologically adapted to shade conditions and could not fully utilize the increase in available light. During the second year after canopy removal, the effect of white pine weevil was minimal. It is also probable that white pine adapted to full sunlight and grew better in clearcuts than shade. If white pine weevil can be controlled, underplanting followed by clearcutting seems a viable regeneration system for eastern white pine in the Piedmont of Virginia.

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SUCKERING AND ROOT CONNECTIONS OF SWEETGUM ON CLAYEY SOIL[1/]

John K. Francis[2/]

Abstract.--An exploratory study of sweetgum suckering on clayey soils of the Mississippi Delta was conducted by completely or partially excavating root systems of 44 individuals varying from new suckers to sawlog-size trees. Position along the root did not influence suckering if the root was thick enough (at least 1/2 inch) to support a sucker. No root appeared too large or old (>150 years) to produce suckers. The average distance measured between suckers and the parent stump was 4.7 feet. Suckering from roots above the soil and as deep as 5 inches was observed. The average depth of sprout-bearing roots was 1.35 inches. Suckers produced from cut trees must develop independent root systems or perish. A sucker typically appropriates the parental root from the sucker outward. Within 1 to 5 years after sprouting, new roots appear directly below the stem and develop gradually. Root connections between suckers may be broken If the connections are small. If the root connections are thick, the trees will remain joined for life.

Root sprouts of sweetgum, often called suckers, are a desirable form of reproduction. They grow rapidly and originate through a wide range of harvest conditions. Suckers are thought less susceptible to butt rots than stump sprouts (Johnson 1964). Kormanik and Brown (1967) reported sweetgum suckers originating from previously formed suppressed buds. They also noted a marked enlargement of the lateral root distal to the point of sprout origin. Hook and others (1970) observed that secondary roots were more abundant on small-diameter parent roots. Height growth of sprouts was positively correlated with parent root size and negatively correlated with distance from stump to sprout. Development of secondary root systems varied somewhat between soil types, according to Hook and others (1970).

1/ Paper presented at Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ Soil Scientist, Southern Hardwoods Laboratory, maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

This exploratory study was undertaken to learn more about sweetgum suckering on the clayey soils of the Mississippi Delta. Sites sampled contained soils from the Sharkey, Alligator, Tunica, Tensas, and Forestdale series. These soils are saturated during winter and spring and may dry and crack during late summer.

METHODS

This investigation was guided by four questions:

1. What are the characteristics of roots from which sweetgum suckers arise?

2. How long does it take new suckers to develop independent root systems?

3. Do root interconnections persist through the life of the stand--or through several generations?

4. Do sweetgum appropriate the connected root systems of individuals that are cut or die?

A total of 44 individual suckers, ranging from new sprouts to pole-size trees in 20 locations, were excavated and described. The following measurements were applied as indicated in the questions: depth from which sprouting occurred; thickness of parent root; distance to parent stump or tree; age of parent root; sprout age and size. The roots of one interconnected clump of small sawlog-size sweetgum were completely excavated and 10 small-to-medium sawlog-size connected groups were excavated deeply enough to expose connecting roots. Also, more than 50 stumps were dug to determine whether live roots sustained by root connections were present. Ranges and means are given, although this study was basically nonquantitative.

OBSERVATIONS AND DISCUSSION

Some observed characteristics of sweetgum roots were associated with sprouting; others were not. The smallest root supporting a sprout was 0.5 inch thick. Roots more than 10 inches thick produced sprouts. Age does not apparently prevent root sprouting in trees. Sweetgums more than 150 years old and greater than 50 inches d.b.h. were observed with new suckers. Minimum age is more difficult to determine. Several small- to moderate-sized roots (0.5 to 2 inches) with sprouts were aged from 5 to 10 years old. Very small (<0.5 inches) and consequently young roots apparently do not sprout. Saplings and small poles, when cut, usually stump-sprout while large trees mostly root-sprout.

While sprouts do not arise at or near the root tips, they may originate anywhere the root is large enough to support them. Distance from sucker to parent tree or stump ranged from 0 to 30 feet. The average distance was 4.7 feet. Root branch order per se does not appear to make any difference to root sprouting ability. While sprouts are probably more common first-order lateral roots because of their size and proximity to the surface, sprouts were frequently observed on second- and third-order laterals.

A root's position relative to the soil surface is important. Although suckers were attached to roots as deep as 5 inches, sprouting was much more frequent near the surface. Average depth of soil covering over sprout-bearing roots was 1.35 inches, not considering suckers arising from roots above the soil surface. Sprouting from exposed roots is common in larger trees. Almost all sprouting occurring under closed canopies is from surface roots or roots covered only by duff. In warm, sunlit situations, sprouts can rise from greater depths. At one site, sprouts were observed coming up through thin asphalt. Common sprouting points along a root are deep roots approaching the surface, shallow roots turning down, and before multiple branching (fig. 1). Severing a root particularly stimulates sprouting of the detached root near the cut. The interaction of heat, light, and disturbance to the parent tree on sprout stimulation is still unclear.

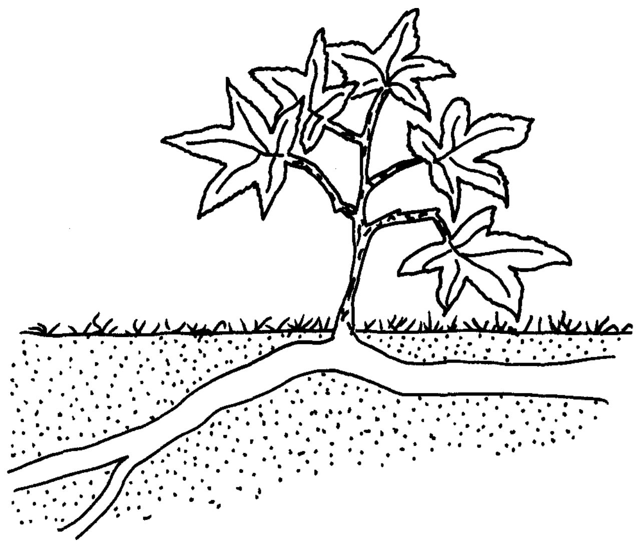

Figure 1.--Typical sweetgum sucker.

The time required for root independence in new suckers cannot be ascertained because the process is gradual. ,A sprout attached to a living tree root or sharing a root with other sprouts may be able to pinch off the connection. This break occurs when the sprout grows thicker at the point of the sprout on the side away from the parent and the root attachment stops growing. A collar is formed and the attachment dies and rots away. The rate at which the root is pinched off decreases with the thickness of the root. A thick root (precise dimension uncertain) will not be pinched off at all.

A new sucker also begins to develop roots in addition to those appropriated from the parent root system. These secondary roots, appearing below the sucker 1 to 5 years after its emergence, develop slowly. They are not prominent until the sprout is 10 to 20 years old. The swollen distal portion of the parent root may dominate the root system through the life of the tree.

More important than independence from root connections is the sprout's ability to produce enough photosynthate to survive. Often after large sweetgums are cut, the new sprouts, unable to support the massive roots under them or establish independence, perish when the roots die a year or two later.

Root connections between suckers can persist through the life of the stand. In stands of sprout origin, large individuals located within a few feet of each other are often connected (fig. 2). Such individuals can be as many as 20 feet apart, but usually only 3 or 4 feet. The connecting roots are large and may partially prevent the suppression of one individual by the other. Sprouts maintain only the portions of the parent root system to which they are attached. As a result, root networks from large trees do not persist from one generation to another. However, if small trees are repeatedly cut, they may develop and maintain root connections over several coppice generations. A 3-generation root network of young **sweetgum** was observed in a firewood cutting area.

It might be argued that connections between closely spaced individuals of the same species are a result of root grafts which commonly unite closely spaced conifers and oaks. This is apparently not the case in sweetgum. Although grafting does occasionally occur, **sweetgum** roots normally intertwine without grafting. **Sweetgum** interconnections, a single root more or less directly between trees, do not have the characteristic bark streaks often associated with grafting.

Sweetgum trees seldom appropriate the connected root systems of other cut cr dead individuals. Usually, root systems and the connecting root die with their top. The two "appropriated" root systems were small in relation to the root that had taken them over.

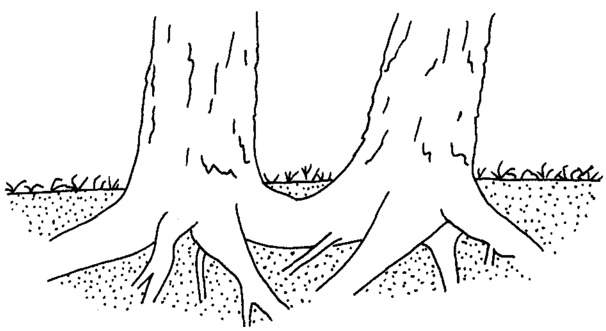

Figure 2.--Root connection between two sweetgums of sucker origin.

SILVICIJLTURAL IMPLICATIONS

Sweetgum can be easily regenerated vegetatively (Kellison and others 1981). Whether root or stump sprouts are produced depends on stand and harvest conditions. Sprouts from roots or the root collar are more desirable than sprouts high on the stump. Sprouting can be forced to a lower position by cutting the stumps very low (Johnson and Krinard 1976) or by removing them entirely. Young **sweetgum** readily stump-sprout but, by 50 years, they lose the ability (Martindale 1965). At the same time, the tendency to root-sprout is increasing. However, size over about 25 inches becomes a liability--the suckers produced are unable to sustain the massive roots from which they arise. Chopping, disking, or other disturbance could alleviate this problem by severing many smaller roots. It would not be necessary to disturb the soil deeply since shallow roots are the ones that sprout.

After a thinning of sweetgum, suckering will occur to a limited extent, but the suckers do not generally survive long enough under shade to be of value as advanced reproduction. No effective gain in root surface occurs in **sweetgum** by removing connected individuals. Root connections could be a liability if chemical thinning is attempted. "Flashback," translocation of chemical from one tree to another, can cause death of some of the remaining trees (Fenton 1965). **Sweetgum** produce suckers all through the growing season. They should respond to cutting similarly to stump sprouts. Dormant season cutting is best for stump sprouting, but any time of the year will do (Wenger 1953).

Sweetgum from suckers grow more rapidly than seedlings and have greater resistance to butt rot than stump sprouts. Where **sweet**gum roots are available for sprouting, suckers should be the preferred form of reproduction.

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TEN-YEAR RESULTS FROM THINNING AN ELEVEN-YEAR-OLD

STAND OF LOBLOLLY PINE ON AN EXCELLENT SITE[1/]

G. K. Xydias, A. H. Gregory, and P. T. Sprinz[2/]

Abstract.--An eleven-year-old stand containing about 640 trees/acre and 3100 cubic feet (ob) per acre in an area where average site quality at age 25 exceeded 80 feet was thinned to residual densities of 100, 200, or 300 trees per acre or left unthinned. Although 40 percent of the trees originally present in the unthinned control have been lost to mortality, this treatment has produced more volume of pulpwood and sawtimber ten years after treatment. Projection of stand attributes with growth and yield models implies that this situation will remain unchanged twenty years after treatment.

INTRODUCTION

The pulp and paper companies in the South have always been ambivalent toward the role of thinning. At one point in time, the concept existed that traditional practices of plantings at close spacing and frequent light thinnings to salvage mortality would be employed. Then as thinning labor became scarce, and numerous studies pointed out that pulpwood production was maximized under a regime of not thinning, thinning fell into disfavor. The widespread use of Chip-N-Saws for the utilization of small sawtimber and predictions of a continued spread between pulpwood and sawtimber prices has again brought thinning concepts into vogue.

Continental Forest Industries, a wholly owned subsidiary of the Continental Group, Inc., was no different in its outlook. It was felt that a study could provide some insight. As a prelude to study establishment, two of the authors of this paper (Xydias and Gregory) examined increment borings from operationally thinned stands of slash pine (*Pinus elliottii* Engelm.) in a vain attempt to determine when that stand had been thinned based on any change in ring width patterns. The only tree we were able to observe increased ring width after a cutting operation was in a core form about a ten-inch residual in a young plantation.

This lead us to feel thatonlya severe thinning would stimulate diameter growth. A great deal of growing stock would have to be sacrificed to accomplish that stimulation. We also reasoned that under conventional planting rates of 600-800 trees/acre, crown ratios would have dropped to twenty percent by the time trees were large enough in diameter to generate enough volume for a commercial thinning. This meant that the stand would be well into the rotation before the first thinning could be done, and that it would take several years for the trees to build up enough live crown to show a response to thinning. By that time, stand age would be close to the normal rotation age, and there would be little opportunity for increased growth. We concluded that if thinning could indeed increase volume production over a 30-35 year rotation that the best chance for it to occur would be on the better sites. If it failed on the better sites, then we felt that there was little hope on the average or poor sites.

THE STUDY AREA

The study area is situated on Continental Forest Industries "Frank Heyward" lease in the southeastern part of Bulloch County, Georgia, a

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few miles north of the Bulloch-Bryan county line. Topography is level throughout the area, and soils are predominantly Stilson (arenic plinthic paleudult). A typical profile will have about 24 inches of fine loamy sand over a sandy clay B2 horizon at depths of about 36 inches. Low chroma mottles begin to appear within 30 inches and more than half of the matrix has low chromas at depths of 35-40 inches. Drainage would be considered as moderate by SCS designations. A portion of the study area is on Fuquay loamy sand. This portion has a fine loamy sandy surface to about 36 inches with a sand clay B2 horizon at about 40 inches. Low chroma mottles begin to appear below 40 inches, but the matrix color remains bright throughout the profile. This portion would be considered as well drained by SCS designations.

The study area was a cultivated field before being planted to loblolly pine (Pinustaeda L.) during the 1959-60 planting season. Seed source is unknown, but is presumed to have been a local variety of loblly pine. The understory consisted of a few scattered individuals of wax myrtle (L.⁄rica cerifera _), but the dominant feature was a layer of pine straw.

TREATMENTS

The study was initiated in the early spring of 1971 when the plantation had completed eleven growing seasons in the field. Four treatments were installed in a randomized complete block design with three replications of each treatment. Two of the blocks were located on the Stilson soils while the third block was situated on the Fuquay soils. Trees in this block did not appear to be as vigorous as those in the former two blocks, although dominant height was similar in all three blocks.

Quarter-acre treatment plots were laid out within each block and the interior tenth-acre served as a measurement plot. Treatments selected for comparison were unthinned control and thinning to residual stockings of 100, 200, or 300 trees/acre. Thinning was from below, except in the more heavily thinned plots, with emphasis placed on leaving well spaced dominant trees rather than in upgrading the stand. Thus many of the leave trees are crooked or forked.

The thinning treatments were imposed during late March 1971, using company personnel. Since there were few shortwood operators in the area at that time all trees were left on site after felling.

MEASUREMENTS

Each tree within the measurement plot was measured at the DBH point prior to thinning and its diameter recorded by row and position within the row. Trees designated as leave trees were tagged with a unique number and identified on the plot tally sheets. Subsequent diameter measurements have been obtained annually except at three, seven, and eight years after treatment. Heights have been obtained more sporadically. When the study was first established, DBH and total height measurements of 30 trees in each block were obtained from the felled trees. Four years after treatment, DBH and total heights were obtained from four to six trees in each plot. Eleven years after treatment, both total height and height to a six-inch (ob) top and DBH were obtained from six to nine trees in each plot. Height measurements were always obtained over the range of diameter classes.

Heights of all trees were determined by regression of the inverse of both diameter and height. This transformation resulted in a linear relationship between diameter and height, and had correlation coefficients of about 0.80 to 0.85. Models for inital and four-year heights did not differ significantly by replication or treatment and so all data were combined into a single regression for each of these periods. Models developed from the eleven-year data did differ significantly by treatment.

Cubic foot volumes (ob) to a 4 inch top were calculated for each tree greater than four inches DBH, using an equation developed by Coile and Schumacher (1964). These volumes can be converted to standard cords (92 cubic feet of wood and bark) by multiplying them by a facor that varies with the diameter of the tree of mean basal area. This factor can be calculated by the following equation:

$$F = 0.0105 + (0.0642/D) - (0.03440/D^2)$$

The inverse of F is the cubic feet of wood and bark in standing trees needed to make a standard cord, and varies from about 86 for sit-inch trees to 74 for nine-inch trees.

All volume calculations were based upon measured diameters and heights predicted from the appropriate diameter-height equations. Fifth-year volumes utilized the fourth-year diameter-height equations and tenth-year volumes utilized the eleventh-year diameter-height equations. Mortality at these two points utilized the appropriate diameter-height equation, applied to the diameter of the tree at the time it died.

Table 1.--Stand attributes before imposition of the thinning treatments by replication and treatment.

Treatment	Attributes by Replication 1	2	3	1	2	3	1	2	3
	--Cubic Feet/Acre--			Basal Area/Acre			--Trees/Acre--		
100	3437	3673	2208	161	174	130	520	616	790
200	3244	3404	2813	154	172	148	550	696	689
300	3387	3592	3160	159	176	162	534	653	687
Control	3517	3437	2865	162	175	151	504	707	683

This probably overstated the volume of mortality trees, since the height of the ith diameter class tended to increase with age, while mortality often occurred earlier than when the diameter height model was derived.

RESULTS

Stand attributes at the time of thinning are given in Table 1 for each of the twelve plots. Dominant height at age 11 was 54 feet, and this is out of the range of most site quality curves. Dominant height at age 22 was in the 80-85 foot range in the first two blocks and about 75 feet in the third block. Initial basal area was reasonably uniform in the first two blocks, but there was more variation than desirable in the third block.

Attributes of trees removed by the thinning and of trees remaining after treatment are given in Table 2. In this and subseauent tables, volumes are for trees that are four inches or larger in diameter, while basal area and number of trees are for all trees. The 100 stem/acre treatment was a severe treatment, removing about 85 percent of the trees and leaving a residual basal area of only 40 square feet.

Table 2.--Stand attributes after thinning by treatment.

Treatment	Cubic Feet	Basal Area	Trees
	Removed by Treatment		
100	2223	117	544
200	1690	92	430
300	1066	62	336
Control	0	0	0
	Remained after Treatment		
100	931	40	101
200	1690	74	195
300	2207	100	295
Control	3106	155	642

Stand attributes five and ten years after treatment are shown in Table 3. The unthinned controls still have the greatest volume, ten years after treatment. Basal area of the 300 trees/acre treatment is approaching the same level that was present in the unthinned controls when the study was initiated, however, volume is greater due to the increase in height.

Mortality losses over the past ten years have been surprisingly modest as measured by both basal area and cubic feet (Table 4). This is true even in the control plots which have experienced a loss of almost 40 per cent of the trees present at age 11.

Table 3.--Stand attributes five and ten years after imposition of the thinning treatments.

Treatment	Cubic Feet	Basal Area	Trees
	Five Years		
100	1799	67	503
200	2776	106	101
300	3336	131	195
Control	4217	176	289
	Ten Years		
100	2755	89	101
200	4048	128	188
300	4752	150	269
Control	5761	186	400

When volumes removed in thinning and lost to mortality are added back in to the initial. volume and growth aver the period, the controls have still outproduced the thinned plots (Table 5). Total production in 300 tree treatment is approaching that of the controls, but the thinned plots still have produced ten to fifteen percent less volume.

A major argument for thinning is that it enhances the production of sawtimber-size trees. Table 6 shows that the unthinned plots have a greater volume of sawtimber-size trees than the thinned plots. If the sawtimber trees are partitioned into the components of small and large sawtimber, with trees in the diameter range of 8-12 inches being considered as small sawtimber, and trees thirteen inches and larger being considered as large sawtimber, only then do the 100 tree and 200/tree/acre plots have more saw-timber volume than the control plots. Actual sawtimber volume differences are probably less than what is shown in Table 6, because not every sawtimber-size tree in the unthinned plots is of sawtimber quality.

Table 4.--Mortality at five and ten years after treatment.

Treatment	Cubic Feet	Basal Area	Trees
	First Five Years		
100	0	0	0
200	0	0	0
300	56	2	7
Control	100	10	117
	Total for Period		
100	40	2	3
200	44	6	173
300	183		
Control	528	29	237

production stands. Dominant heights in the range of 80-85 feet at age 22 imply a productivity level that is seldom exceeded. Yet results obtained to date are similar to those of other thinning studies in loblolly pine (Sprinz and others 1979, Burton 1980, Burton 1981, Mann 1952, Belanger and Brender 1968) or in slash pine (Enghardt and Mann 1972, Bennett 1969). That is, the unthinned plots produce more total volume but have trees of smaller average diameter. Other researchers have shown that similar trends have occurred in spacing studies (Harms and Lloyd 1981, Smith 1967, and Shepard 1974). Wakeley (1969), however, reported that a single commercial thinning in variously spaced slash and loblolly pine at age 15 did not have any effect on yields at age 30 when final yields plus volume removed in thinning was considered. However, the thinning levels in that study were not as wide as they were in this study.

Table 6.--Volume in sawtimber-size trees (MBF International) after 21 growing seasons

Treatment	Sawtimber-Size Small (8-12 in.)	Large (13 in.+)	Total (8 in.+)
	- - MBF International/Acre-		-
100	0.9	2.2	3.2
200	2.6	1.3	4.0
300	3.3	0.9	4.2
Control	4.0	1.0	5.1

Table 5.--Cubic foot production over the 21-year-life of the stand

Treatment	Initial	Removals Thinning	Mortality	Growth	Total
	- - - - - - - - - - Cubic Feet/Acre-		- - - - - - - - -		
100	931	2223	40	1824	5018
200	1690	1690	44	2358	5782
300	2207	1066	183	2545	6001
Control.	3106	0	528	2655	6289

DISCUSSION

There is little doubt that this study area is on a highly productive site. It rivals the plantation reported by Langdon and others (1970) in an informal challenge to identify highly

Mean diameter of trees at close spacings is generally smaller than at wide spacings, due to the inclusion of the smaller intermediate and suppressed trees in the average. Some researchers have reported no difference in average diameter between thinned and unthinned stands when that average is based on the same number of trees (Wakely 1969, Enghardt and Mann 1972, Keister 1967, Andrulot and Williston 1974). In this study, differences in average diameter of the largest 100 trees per acre became apparent very early in the heavily thinned plots and have persisted throughout the study period (Table 7).

What will happen on this study is uncertain but it can be inferred from growth and yield models. Two different approaches were followed. One approach was to derive a basal area projection equation using data from this study. The equation utilized a model adopted from Burlchart and Sprinz

Table 7 .--Average diameter of the largest 100 trees/acre.

Treatment	Time Period			
	Establishment	5 Years	10 Years	10-Year Increase
	Diameter in inches			
100	8.5	10.9	12.6	4.1
200	9.1	11.0	12.4	3.3
300	9.2	10.7	11.5	2.3
Control	9.5	10.9	11.9	2.4

There are currently more sawtimber-size trees on the control plots and consequently a greater sawtimber volume. This is contrary to expectations that thinning should increase sawtimber volume. It is consistent with the results of Burton (1980), who showed in the 'Sudden Sawlog Study', that while heavily thinned plots had more sawtimber volume at age 18 than the control plots, all differences had disappeared by age 33. The thinning treatments accelerate ingrowth into the sawtimber category, but any gains narrow as ingrowth occurs in the control plots. This is illustrated by Table 6 where the unthinned plots have a greater volume of small sawtimber than the thinned plots and less large sawtimber.

Mann (1952), suggests that unthinned natural stands will usually show more cubic foot production until somewhere around age 35 when heavy mortality reduces yields on unthinned plots. In this study even though 40 percent of the trees in the control plots have been lost to mortality, very little volume has been lost. This will undoubtedly change in the future. Other researchers have reported that thinned plots produce more total volume than unthinned controls. Wilson (1955), reported that thinned plots of red pine (Pinus resinosa Ait) produced one percent more cubic volume and thirty-two percent more board foot volume at age 41 than unthinned plots. Wahlenberg (1955) reported that thinned plots of eastern white pine (Pinus strobus L.) produced thirty-five percent more cubic volume and fifty percent more board foot volume at age 56 than unthinned plots, however, the 80-year results from the same study area suggested that cubic foot and board foot yields were similar for both the thinned and unthinned plots (Della-Bianca, 1982).

(1982), and has the form:

$$L_nBA_2 = L_nBA1 * (A_1/A2) + bo * BA1 * (1-A1/A2)$$

where Ln = natural log
BA1 and BA_2 = basal areas at age A1 and A2 respectively
bo = regression coefficient

Analysis suggested that use of a separate coefficient for each thinning level gave a slightly better fit to the data than use of a common coefficient. The improvement in accuracy by using separate coefficients was not large however.

Solution of this equation using separate coefficients for each treatment showed a very good fit between actual and predicted basal areas throughout the ten-year life of the study. Extrapolation of the equation to age 26 and 31 implies that basal area of the control plots will stabilize at about 200 square feet with basal area of the thinned plots falling below this level (Figure 1). Note that all of the curves are tending toward diminishing basal area growth even within the range of the observed data. Since volumes are largely dictated by basal area when site quality is held constant, this suggests that standing volume will always be greater in the unthinned plot.

Burkhart and Sprint (1982) present projection equations for estimating both cubic volume and board foot volume in thinned loblolly old field plantations based upon stand attributes at the time of thinning. These equations are derived from a data set consisting of one to three observations of 103 permanent plots throughout the Piedmont and Coastal Plain of Virginia, Solution of these

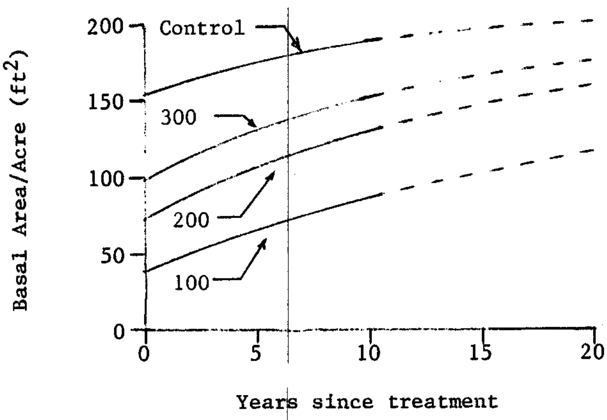

Figure 1. Trends in actual and projected basal area

equations using stand attributes of this study ten years after thinning as a base or at age 21, and projecting the stand forward to age 41 in five-year increments was the basis for the second approach. Results suggest that both total volume and board foot volume will be greater in the control plots at all ages in the projection period. This is contrary to projections of the thinned stand model developed by Clutter and Jones (1981) for a similar data base but for slash pine; however, these differences may be explainable by differences in the growth habits of the two species.

Data from this and other studies, and the results from the projection of growth and yield models suggest that thinning will not enhance sawtimber volume in the long run. Conclusions arrived at from projections of growth and yield models should be viewed with caution since extrapolation beyond the limits of the data base for any model can lead to erroneous results. Even if the extrapolations used here are realistic, such results do not necessarily imply that thinning has no role in plantation management. It can alter wood flows and result in trees of larger average diameter which should in turn lower harvesting costs. This may result in a better unit price for the same commodity than in an unthinned stand. Thinning will stimulate diameter growth particularly for the larger trees and will reduce the time in which more valuable sawtimber-size trees can be produced, however, this early advantage will be lost as trees attain the threshold diameter for sawtimber in the unthinned stands.

In summary, thinning should not be viewed as a means of increasing production by the salvaging of mortality under rotation lengths commonly employed by forest industry. It is a means of meeting mill requirements without the need for costly site preparation and planting, and to improve the financial return at harvesting in those areas where the same volume of wood is more valuable as sawtimber than as pulpwood.

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PRECOMMERCIAL THINNING FOR THE PRIVATE, NONINDUSTRIAL LANDOWNER: A METHODOLOGY REPORT[1/]

Michael D. Cain [2/]

Abstract.--Precommercial thinning in dense stands of loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine is a proven management technique for increasing diameter growth on residual stems. Four precommercial thinning methods (mechanical strip-thinning, selective hand-thinning, soil-applied herbicide, and prescribed fire) are discussed. These thinning methods provide management alternatives for private, nonindustrial landowners who hold over 70 percent of the commercial forest land in the South.

INTRODUCTION

Considerable research has been done emphasizing the need for precommercial thinning in young loblolly pine stands (Bower 1965, Grano 1969, Jones 1974, Keister and McDermid 1968, Lohrey 1972 and 1977, and Williams 1974). When properly executed, such thinnings can increase the growth and shorten the rotation of crop trees. In addition to promoting growth, precommercial thinning often increases forage for livestock and wildlife and reduces risks from losses by fire, insects, diseases and weather (Mann and Lohrey 1974).

Several alternatives are available for precommercially thinning young pine stands. This paper discusses four techniques (mechanical strip-thinning, selective hand-thinning, soil-applied herbicide, and prescribed fire) currently being tested in a series of studies in south Arkansas, describes their advantages and disadvantages in application and includes some preliminary results. The best alternative for field application may depend on whether the stand is even-aged or uneven-aged.

1/ Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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METHODS

Study Areas

The four precommercial thinning studies are located on the Croesett Experimental Forest in Ashley County, Arkansas. The soil on the Experimental Forest is principally Bude silt loam (Glossaquic Fragiudalfe), but some Providence silt loam (Typic Fragiudalfs) is associated with it (USDA 1979). Both soils are loessial deposits with an impervious layer at 18 to 40 inches that impedes internal drainage, Both have high potential productivity for loblolly pine with a site index of 90 feet at 50 years. Seasonal wetness may limit the use of equipment for woodland management.

The studies utilizing mechanical strip-thinning and prescribed fire are located on a lo-acre area, originally occupied by a mixed pine/hardwood stand, which was cleared in 1971 for a research planting area. In 1972, pine seeded in from adjacent stands, but that reproduction was mowed in the fall of 1973 to maintain a site-prepared area for planting. In 1974-75, the area reseeded naturally with loblolly and shortleaf pine and remained undisturbed until 1979. At that time an inventory was conducted and the area was found to contain an average of 16,600 pine seedlings per acre.

Plots for the studies involving selective hand-thinning and soil-applied herbicide are located throughout the Experimental Forest in dense patches of advanced pine reproduction. The stands in which these plots are located are made up of a mixture of loblolly and shortleaf pine managed under the selection system since the 1930's. Reproduction density on these plots ranged from 1,000 to 6,000 pines per acre for stems less than 4 inches dbh at the time of treatment.

Study Installation

Mechanical Strip-Thinning

Following a pretreatment inventory in the fall of 1979, twelve plots of square or rectangular configuration (0.4-acre each) were established. Two treatments--mechanical strip-thinning and controls--were assigned in a completely randomized design.

Thinning was done in October 1979 using a six-foot-wide, heavy-duty rotary mower (Bush Hog, Model 406) attached to an industrial-size, wheeled tractor (Ford 532, diesel). Cut swaths were 12 feet wide and alternated with 1-foot-wide uncut strips.

Total height was measured to the nearest 0.5 foot and dbh to the nearest 0.1 inch on all living pines within systematically established subplots representing a 3-percent sample of an interior 0.2-acre measurement plot. These measurements were taken in the fall of 1979 after thinning and again in the fall of 1981. Individual tree data were averaged on a plot-by-plot basis. Pine cubic-foot volumes were computed from height and diameter data (Perry and Roberts 1964). The 1981 growth differences between treatments were tested for significance by analysis of variance at the 0.05 level.

Selective Hand-Thinning

In October 1980, 36 circular plots of 0.05 acre each were established in dense patches of advanced pine regeneration within uneven-aged stands. Pine reproduction (1 to 4 inches dbh) averaged over 1,000 stems per acre on 0.02-acre measurement plots within the 0.05-acre gross plots. Some plots also contained pulpwood size (4 to 7 inches dbh) and/or overstory pines (7-inch or larger dbh classes); these stems were used for calculating a pretreatment competition index (Daniels 1976). Plots were stratified according to initial percent stocking of pine (McLemore 1981); then four thinning treatments, with 9 replications each, were assigned at random.

The four treatments included a control, thin to 800 stems per acre, thin to 500 stems per acre, and thin to 200 stems per acre. These selected treatments were based on recommended post-thinning densities for rapid diameter growth in even-aged loblolly pine stands (Mann and Lohrey 1974). Well-formed dominants and codominants were left to provide uniform spacing.

Hand thinning was done in October 1980 by a two-man crew using one small chain saw and one machette. Hardwoods were stem injected with undiluted Tordon 101R inside the boundary of each 0.05-acre plot in the spring of 1980, prior to thinning.

After thinning in the fall of 1980, residual pines on thinned plots plus 800 pretagged dominants and codominants per acre on control plots were measured. Total heights were taken to the nearest foot and dbh to the nearest 0.01 inch. In the fall of 1981, all surviving pines were remeasured and means calculated on a plot-by-plot basis. Cubic-foot volumes were computed from height and diameter data (Perry and Roberts 1964). After five years, growth data will be subjected to covariance analysis with pretreatment competition index and pretreatment percent stocking as concomitant variables.

Soil-Applied Herbicides

In March 1980, 16 circular plots of 0.05 acre each were established in dense patches of advanced pine reproduction within uneven-aged stands. For stems less than 4 inches dbh, over 2,000 pines per acre and up to 3,000 hardwoods per acre were recorded on these plots. Plots were blocked on the basis of initial pine density and four treatments were assigned at random within each block to test the efficacy of Velpar^R (hexazinone) for precommercially thinning pine reproduction and for controlling hardwoods.

We used 2cc Gridball^R pellets (10 percent active ingredients) for the treatments that included: control; 2 lbs. a.i./acre on a grid of 4.25 feet by 4.25 feet; 4 lbs. a.i./acre on a grid of 3 feet by 3 feet; and 6 lbs. a.i./acre on a grid of 2.45 feet by 2.45 feet. The pellets were hand placed in late April 1980 during clear and warm weather. Over the next four weeks, rainfall accumulation at the Experimental Forest was 8.75 inches. At least 3 to 4 inches of rainfall are needed for soil activation of the chemical (E. I. DuPont 1979).

In March 1980, all living pines and hardwoods within each 0.05-acre plot were measured at dbh to the nearest 1-inch class. Stems ≤ 3.5 inches dbh were categorized as understory regeneration, and those ≥ 3.6 inches dbh as overstory. Pine and hardwood data were summarized separately by understory and overstory components on a plot-by-plot basis. In the fall of 1981, all surviving stems were remeasured to determine the effect of Velpar^R on pine and hardwood density by size class.

Prescribed Fire

In February 1982, a 0.35-acre plot and a 0.50-acre plot were established in an 8-year-old natural stand of loblolly/shortleaf pine regeneration. Pine density averaged 12,000 stems per acre with 48 percent of the stems ranging in height from 10 to 28 feet. All other pines were less than 10 feet tall.

Both plots were prescribed burned using backfires set with a 4:1 diesel oil/gasoline mixture from a drip torch. Burning on the 0.35-acre plot began at 11:45 a.m. on February'22. Wind speed was 6 mph from the SE; temperature was 76° F; relative humidity was 26%; and fine fuel moisture was 6%. There was no precipitation recorded 6 days prior to burning, but drying potential was poor until one day preceding the bum.

Burning on the 0.5-acre plot began at 12 noon on March 8. Wind speed was 6 mph from the SW; temperature was 60° F; relative humidity was 30%; and fine fuel moisture was 6%. Precipitation within 7 days preceding the bum was over a 12-hour period, ending 48 hours prior to burning with a 0.75-inch accumulation.

Prior to burning, total height to the nearest 0.5 foot and dbh to the nearest 0.1 inch were measured on all living pines within 21 systematically established milacre subplots representing 2.5 percent of the area to be burned. Data were summarized by three height classes (≤4.5 feet, 5.0 to 9.5 feet, and 10 feet).

Before burning, ground fuel samples were taken for weight determination within 3 randomly established 0.02-milacre subplots near the center of the burn area. Samples consisted of all litter down to mineral soil. These samples were air-dried for 48 hours prior to weighing. Three additional samples were taken within 24 hours after the burn.

Shortly after the burn, height of stem bark char was measured to the nearest 0.1 foot on each surviving pine within the 21 preestablished subplots. These data were taken as an estimate of flame height (McNab 1977) and used for calculating fire intensity (Byram 1959).

In early summer 1982, all surviving pines on preestablished subplots were remeasured to the nearest Ci.5 foot in height and 0.1 inch dbh to determfne change in density by size class following the fire.

RESULTS AND DISCUSSION

Mechanical Strip-Thinning

This thinning technique resulted in an 89 percent reduction in pine density. Of the residual 1,920 pines per acre following thinning, 650 were ≤4.5 feet tall, 860 were between 5.0 and 9.5 feet tall, and 410 were ≥10 feet tall. Stems 10 feet and taller at the time of thinning will probably become the crop trees. A time trial, as part of this study, showed that thinning could be done on a production basis at the rate of 1.5 acres per hour.

Two years after thinning, mean diameters of dominants (≥10 feet in height) on thinned plots were significantly larger than those on control plots (table 1). Mean heights and cubic-foot volume per tree for dominants did not differ significantly between treatments.

Table 1. - -Measurements on pines 10 feet and taller, two years after mechanical strip-thinning

Treatment	Diameter breast height	Total height	Volume per tree
	Inches	Feet	Cubic feet
Control	1.49 a*	14.9 a	0.20 a
Thinned	1.94 b	14.0 a	0.24 a

* Within-column means not followed by the same letter are significantly different (0.05).

From 1979 to 1981, pine density on control plots declined by more than 2,000 stems per acre, leaving approximately 14,500 stems, as a result of natural mortality. Density on thinned plots remained at about 2,000 stems per acre over the same two-year period.

Selective Hand-Thinning

Even though pine density on control plots averaged over 1,400 stems per acre, the 1981 annual growth of pretagged pines was equal to that of pines on plots thinned to 800 and 500 stems per acre (table 2).

Table 2. - - Growth of surviving pines in 1981 on plots that were selectively hand thinned

Treatment	Mean annual growth per tree: DBH	Height	Volume
	Inches	Feet	Cubic feet
Control (800 Dom-Codom/acre)	0.14	1.08	0.07
800 stems/acre	.14	.80	.05
500 stems/acre	.16	.92	.05
200 stems/acre	.27	1.11	.16

At 200 stems per acre, annual pine growth in diameter and volume was nearly twice that of pines in other treatments. Competition from overstory pines in these all-aged stands probably contributes to the slow growth rate of understory regeneration, and it is too early to speculate as to which precommercial thinning regime insures optimum growth under these conditions.

Hand thinning a 15-year-old natural stand of loblolly pine from 5,000 stems to 680 stems per acre resulted in accelerated diameter growth over a three-year period (Bower 1965). On relatively small areas, as tested in the present study, selective hand-thinning may be an alternative to other precommercial thinning techniques, because thinning time averaged only 4 to 7 minutes per 0.05-acre plot.

Soil-Applied Herbicide

Density of pines and hardwoods was monitored for two growing seasons following herbicide application. During that two-year period, density of pines less than 4 inches dbh declined on control plots as much as on chemically treated plots (table 3).

Table 3. -- Percent decrease in pine and hardwood stems <4 inches dbh using soil-applied herbicide

Treatment	Change in stocking after two growing seasons: Pine	Hardwood
	-------percent---------	
Control	-20	-9
2 lbs a.i./acre	-22	-58
4 lbs a.i./acre	-16	-56
6 lbs a.i./acre	-21	-81

Since pine density averaged over 1,000 stems per acre, two years after treatment, Velpar[R] Gridballs[R] were ineffective for precommercial pine thinning on silt loam soils at the rates tested.

The decline in hardwood density was directly related to the herbicide treatment, with the highest rate of application being the most effective for control of hardwoods less than 4 inches dbh. Overstory hardwoods were more easily controlled than understory stems, probably because more of their root systems were in contact with the herbicide.

On lighter textured soils than those in this study, Velpar[R] Gridballs[R] may be useful for precommercial thinning of pine regeneration. Southern pine seedlings less than five years of age will most likely be injured or killed by this chemical (E. I. DuPont 1979). However, pine saplings and pine trees appear to be more tolerant to Velpar[R] if the trees are not stressed by insects, diseases or climatic factors.

Prescribed Fire

The rate of spread for the burns averaged 2.3 feet per minute with an average flame height of 1.7 feet. Ground fuel, consisting mainly of pine litter and grasses, weighed 3.9 tons per acre (air-dry) before the fire and 1.1 tons after burning.

Burning reduced pine density from 11,917 to 5,876 stems per acre. Most of that reduction was in stems less than 10 feet tall (table 4). Mortality of pines in the larger size class was negligible.

Table 4. -- Pine measurements before and after prescribe burning

Variable	Height class: ≤ 4.5'	5.0 to 9.5'	≥ 10'	Totals	Weighted means
	---------Stems/acre----------				
Density					
Before	3,431	2,722	5,764	11,917	
After	0	570	5,306	5,876	
	----------------Feet-------------------				
Total Ht.					
Before	2.4	7.1	16.2		10.7
After	--	8.0	17.6		16.7
	---------------Inches-----------------				
DBH					
Before	--	0.27	1.64		1.24
After	--	0.42	1.78		1.66

Fire intensity was calculated as 17 Btu per second per foot, which is comparatively low according to Byram (1959). A low intensity burn is also indicated by the high rate of survival following treatment. Because pine density was extremely high and average dbh of the tallest stems was less than 2 inches, hotter fires could have destroyed the stand. More effective precommercial thinning with fire has been achieved in southern pine stands having a wider range of diameters and lower densities than those found in this study (McNab 1977, and Nickles, et al. 1981).

SUMMARY AND CONCLUSIONS

Past research suggests that rapid diameter growth of even-aged loblolly pines can be achieved when density is reduced to less than 1,500 stems per acre by precommercial thinning. But a density between 500 and 800 stems per acre may maximize volume gains. To accomplish that goal, several thinning techniques are available, but each has advantages and disadvantages in practical application. Techniques that are best suited for even-aged stands may be undesirable for use in uneven-aged conditions.

Mechanical strip-thinning is widely practiced in the South because of its precision in application. Rotary mowing is most efficient between ages 2 and 5 years; then stems are easily severed and visibility for the tractor operator is high. Costs will depend on the type of equipment, size and density of stems being thinned, experience of the operators, and physical obstacles on the area being thinned. The main **disadvantage of this technique is the cost of heavy** mechanical equipment.

The main advantage of selective hand-thinning is that it permits individual trees to be retained on the basis of form and spacing. Although hand-thinning is considered too costly to be practical on large acreage, it may be the only alternative for the private, nonindustrial landowner on small woodlots.

Although ineffective for precommercial thinning of advanced pine reproduction on silt **loam soil, at the rates** tested, Velpar[R] **Gridballs**[R] **are considered to be effective for releasing pines from overstory hardwood competition. The main advantage of this technique is that no expensive equipment is necessary for field application. Users are advised to follow label directions when** applying herbicides.

Prescribed fire, as a precommercial thinning technique, is useful for treating large areas at relatively low cost. However, this technique **lacks precision in application. When using fire,** individuals must be aware of appropriate weather **conditions, size and density of the pines being** thinned, amount of combustible ground fuel, and **must abide** hy State **burning laws.**

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RESULTS AFTER 21 YEARS IN PRECOMMERCIALLY THINNED DIRECT-SEEDED SOUTHERN PINE STANDS[1/]

Robert M. Farrar, Jr.[2/]

Abstract.--Results of a precommercial thinning to a nominal 8x8-ft spacing at age 3 in broadcast direct-seeded stands of the four major southern pines in the East Gulf are reported when stands are 21 years old. In loblolly, shortleaf, and slash pines, thinning resulted in significantly fewer total trees per acre and larger mean diameters than no thinning but total stand volumes were not significantly different. Thinning apparently concentrated the volume into fewer larger trees, The average difference in merchantable volume between thinned and unthinned stands was not significant. However, where survival was good for both treatments, about twice as much merchantable volume was observed in thinned stands. Overall, loblolly was significantly more productive than shortleaf but not significantly more productive than slash. Longleaf and shortleaf appeared similar in volume production and the limited longleaf data did not indicate any effect of thinning.

Broadcast direct-seeding and natural regeneration of southern pines often result in very dense stands of reproduction containing several thousand established seedlings per acre. It is generally accepted that early merchantable volume production can be improved by thinning these stands to leave densities that approximate planting densities, or 600 to 1,000 stems per acre. Such precommercial thinning is most easily done by hand or with light mechanical equipment when stems are neither too small nor too large to be easily cut. This stage will usually occur at about age 3 to 5 years. Recent developments in self-propelled chippers, which harvest presently sub-merchantable stems principally for fuelwood, hold promise that precommercial thinnings will generally become commercial thinnings in the future.

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This paper presents the results, at stand age 21 years, of a limited precommercial thinning trial imposed at age 3 in broadcast direct-seeded stands of the four major southern pines.

METHODS

Study Area

During the winter of 1956-57 a broadcast direct-seeding trial was installed in South Alabama and Northwest Florida to test operational seeding techniques recently developed by the Southern Station at Alexandria, LA. A randomized complete block containing 4 rectangular l-acre plots was laid out at each of 3 locations. All study blocks are on sandy uplands in the longleaf pinehills of the middle coastal plain. The Escambia block is located on the Escambia Experimental Forest near Brewton in Escambia County, AL. The soils here are mostly a Troup fine sand with some Orangeburg fine sandy loam (SCS 1975). The Miller block is nearby on the lands of the T. R. Miller Mill Company. Its soil is a Dothan fine sandy loam (SCS 1975). The St. Regis block is located on lands of the St. Regis Paper Company near Pace in Santa Rosa County, FL. The soil here is a Troup loamy sand (SCS 1980).

Site preparation varied among blocks. The Miller and St. Regis blocks were on cut-over **longleaf** land. The Escambia block was an abandoned agricultural field. The Miller block was clear-cut and cleared during the summer of 1956, after which the debris was piled with a root-rake and burned in the following November. The St. Regis block was clear-cut in 1954 and burned in October 1956. The Escambia block was plowed in early summer, 1956, **disked** in late summer and grazed by cattle between disking and seeding.

In each block, a l-acre plot was randomly assigned to one of four species: loblolly pine (*Pinus taeda* L.), **longleaf** pine (*P. palustris* Mill.), **shortleaf pine** (*P. echinata* Mill.), or slash pine (*P. elliottii* Engelm. var. *elliottii*). During the winter of 1956-57, each plot was broadcast seeded by hand with approximately 10,000 viable **repellent-**treated seed. The loblolly and slash pine seed were from Florida sources, the **longleaf** came from a Louisiana source and the shortleaf was from an Alabama source. Inventories at age 1 and 2 years from seeding are **summarized** in Table 1. These data are based on 10 milacres per l-acre plot. All plots were regarded to be successfully regenerated at age 2 and the.seeding study was closed. However, since average densities varied from about 4,000 to nearly 6,000 stems per acre, precommercial thinning treatments were imposed on the stands and the plots were maintained as a demonstration.

Thinning Treatments

Precommerclal thinning treatments were made in the loblolly, shortleaf, and slash pine plots in the winter of 1959-60, at age 3, when one-half acre of each l-acre plot was randomly selected and thinned in each block. Thinning was done by hand with machetes to leave the better-formed and most vigorous stems at an approximate 8x8-ft spacing or about 681 trees per acre. Thinning required about 2 man-hours per **½-acre** plot. The **longleaf** plots were not thinned at age 3 because prescribed burning for brownspot needle disease (*Scirrhia acicola* (Dearn.) Siggers) control was required on the Miller and St. Regis plots at that age. **Long-**leaf thinning was deferred to age 5 to allow any mortality resulting from burning to occur prior to thinning.

The stand data for the thinned and unthinned plots at age 5 is summarized in Table 2. These data are based on 25 four-milacre plots per **½-acre** treatment plot inventoried to assess stocking, stand density, and the average d.b.h. and height of the dominant trees. At age 5, only the **long-**leaf +-acre plot in the Escambia block, with 6,190 stems per acre, was thinned to leave 710 stems. Although the Miller **longleaf** stand averaged 3,115 stems per acre, it and the St. Regis **longleaf** stand did not receive a thinning treatment because many of the seedlings were small. For the other three species, thinning left average densities varying from 690 to 713 trees per acre while the averages for unthinned stands varied from 2,538 to 4,993 stems per acre.

Table 1.--Average.stocking and density of seeded stand at ages 1 and 2 years and dominant height at age 2.

Species	Location	Stand Age = 1 year		Stand Age = 2 years		
		Stocking[1/]	TPAO[1/]	Stocking[1/]	TPAO[1/]	DH[2/]
		%	No.	%	No.	ft
Loblolly	Escambia	90	5,600	90	5,400	2.0
	Miller	90	12,500	90	11,100	1.8
	St. Regis	60	1,500	50	800	1.2
	Average	80	6,533	77	5,767	1.7
Longleaf	Escambia	80	2,000	80	2,000	0.2
	Miller	100	7,900	100	7,100	0.1
	St. Regis	50	4,200	50	3,800	0.1
	Average	77	4,700	77	4,300	0.1
Shortleaf	Escambia	100	9,500	100	9,300	1.4
	Miller	[illegible]	3,900	70	2,700	1.2
	St. Regis	80	5,000	80	4,700	1.2
	Average	~~80~~ 87	6,133	83	5,567	1.3
Slash	Escambia	50	3,500	40	2,800	1.8
	Miller	100	5,900	100	5,000	1.7
	St. Regis	80	4,500	70	4,000	1.2
	Average	77	4,633	70	3,933	1.6

1/ Milacre stocking and total stems per acre (TPAO) based on systematic sample of 10 milacre per l-acre plot per location.

2/ Average height of dominant seedling (DH) nearest center of each milacre.

Table P.--Average stocking, density and dominant stand data for thinned and unthinned stands at age 5 years.

		Loblolly				Longleaf				Shortleaf				Slash			
Treatment	Location	Stocking 1/	TPAO 1/	DDBH 2/	DH 2/	Stocking 1/	TPAO 1/	DDBH 2/	DH 2/	Stocking 1/	TPAO 1/	DDBH 2/	DH 2/	Stocking 1/	TPAO 1/	DDBH 2/	DH 2/
		%	no.	in.	ft.	%	no.	in.	ft.	%	no.	in.	ft.	%	no.	in.	ft.
thinned	Escambia	96	720	2.3	12.1	100	710	0.1	2.9	84	700	1.8	10.0	100	710	2.3	12.2
	Miller	100	710	1.3	10.0			-	-	96	690	1.0	8.0	100	720	0.9	6.4
	St. Regis	80	640	0.7	6.9			-	-	92	720	0.3	4.7	96	710	0.8	6.0
	Average	92	690	1.4	9.7	loo	710	0.1	2.9	91	703	1.0	7.6	99	713	1.3	8.2
not thinned	Escambia	92	4.640	2.0	13.1	100	3,230	0.1	2.0	92	5.970	1.5	9.1	100	2.230	1.8	10.8
	Miller	96	4.500	1.3	10.8	3/ 100	3,115	0.1	1.0	96	6,120	0.8	7.6	100	2,790	1.1	8.2
	St. Regis	80	Boo	0.9	7.7	3/ 94	1,615	0.0	0.7	100	2,890	0.4	5.2	8%	1,370	1.1	7.4
	Average	89	3,313	1.4	10.5	98	2,538	0.1	1.1	96	4,993	0.9	7.3	96	2,283	1.3	8.8

1/ Four-milacre stocking and total trees per acre (TPAO) based on systematic sample of 25 4-milacre plots per ½ acre plot per location.

2/ Arithmetic mean d.b.h. (DDBH) and height (OH) of daninant stem nearest center of each 4-milacre plot.

3/ Two unthinned ½-acre longleaf plots at Miller and St. Regis location, no thinned plots.

Management Treatments

The **longleaf** stands were treated for brownspot control. The Miller and St. Regis stands were spot-sprayed (about 1 seedling per milacre) with Bordeaux mixture at age 1½ years and prescription burned *at age 3.* The Escambia stand, spot-sprayed with Bordeaux at ages 1½ and 3, was not burned because brownspot infection was so severe at age 3 **that** destruction of the stand was feared.

A few residual pines were cut from the Miller block at age 3. Sprout stands of scrub hardwoods on the Miller and St. Regis blocks were controlled by injection at age 4 along with a sparse stand of residual **longleaf** "whips" on the St. Regis block. All plots at the Miller location were prescription burned at age 7 for hazard reduction. No further burning was done at any location until after age 21.

The stands of loblolly, shortleaf and slash pines in all blocks have not been treated for disease or insect control except **that** which occurred through precommercial thinning,

Age 21 Inventory

In the winter of 1977-78, at *age* 21, all plots were inventoried. A k-acre net plot was established in each s-acre gross plot and all living stems were tallied by l-inch d.b.h. classes. D.b.h. was measured to **1/10-inch** and total heights to the nearest foot on a systematic sample of approximately **1/8** of the stems in each l-inch class. Published volume regressions were used to estimate the total and merchantable cubic-foot volume (inside bark) of each sample tree. Volume/basal area ratios for each l-inch class were then calculated from the sample tree volumes and basal areas. The ratios were used to expand the basal area in each d.b.h. class to a plot volume per class. The d.b.h. class volumes were summed and expanded to a per acre basis. The following sources of tree volume functions were used: (1) for loblolly, all **trees-** Smalley and Bower **(1968a);** (2) for longleaf, all trees - Farrar (1981); (3) for shortleaf, all trees - Smalley and Bower **(1968b);** (4) for slash trees c 5 inches d.6.h. - Schmitt and Bower (1970); trees $\geq$ 5 inches d.b.h. - Moehring et aL (1973).

Analysis

Analysis of variance (SAS **1979),** using a randomized block split-plot design with species as major plots and thinning as minor plots, was used to determine the significance of differences in responses measured at age 21. The response variables (per acre) were:

DH = mean height of the dominant stand **(ft)**
TPA1 = number of trees, l-inch d.b.h. class and larger
TPA5 = number of trees, 5-inch d.b.h. class and larger
BA1 = basal area for **TPA1** (ft^2)
BA5 = basal area for TPA5 (ft^2)
DBH1 = quadratic mean d.b.h. for **TPA1** (in.)
DBH5 = quadratic mean d.b.h. for TPA5 (in.)
VOL1 = total cubic-foot volume, inside bark, for **TPA1**
VOL5 = merchantable cubic-foot volume, i.b., for TPA5 and to a 4-inch d.o.b. top.

Duncan's multiple range test was used to determine the significance of mean differences among species. All tests were made at the 5% probability level.

RESULTS AND DISCUSSION

Responses to Treatment

The overall average responses *to* thinning *are* shown in Table 3. Table 3 also shows differences in three species--1ongleaf was not included because it was thinned at only one location. Thinning resulted in significantly larger mean diameters and fewer total trees per acre. None of the means for other responses were significantly different and no species x thinning interactions were significant. These results are interpreted to mean that precommercial thinning done at age 3 did have an overall effect by age 21, primarily by concentrating the total volume in fewer larger trees. Although merchantable mean diameter was significantly larger in the thinned stands, none of the other merchantable stand responses were significantly different. Thus, the majority of evidence suggests that by age 21, precommercial thinning had *no* effect on merchantable stand production. Assuming 80 merchantable cubic feet, inside bark, per cord, the average yields at age 21 are about 22.1 cords for thinned stands and 15.5 cords for unthinned, a difference of 6.6 cords.

Loblolly pine generally was the superior performer overall followed by slash pine and then shortleaf pine (Table 3). The dominant height, mean diameters, and volumes for **loblolly** were significantly larger than those of shortleaf and averaged larger, although usually not significantly, than those of slash pine. The average merchantable yields by species are about 25.9, 12.5 and 18.0 cords at age 21 for loblolly, shortleaf and slash pine,. respectively.

Table 3.--Average response to treatment[1]

Treatment Category[2]	DH	TPA1	BA1	DBH1	VOL1	TPA5	BA5	DBH5	VOL5
	RESPONSE								
(Minor)	ft	no.	ft^2	in.	ft^3	no.	ft^2	in.	ft^3
Thin	52.4a	790b	115a	5.3a	2,176a	409a	99a	6.6a	1,771a
No thin	49.1a	1,438a	124a	4.2b	2,043a	378a	78a	6.0b	1,239a
(Major)									
Loblolly	57.4a	855b	126a	5.6a	2,535a	433a	107a	6.7a	2,074a
Shortleaf	42.0b	1,464a	113a	3.9b	1,691b	327a	67b	5.9b	999b
Slash	52.8ab	1,023b	119a	4.9ab	2,103ab	420a	90ab	6.2b	1,442ab

1/ Within each treatment category, means in each column followed by the same letter are not significantly different (5% level).

2/ Each minor treatment grand mean based on nine ¼-acre plots; each major treatment grand mean based on six ¼-acre plots.

Observations

The lack of a significant difference between thinned and unthinned stands in merchantable volume was unexpected. This was probably caused by the few replications and the existing variation at the time of inventory. There were only 9 pairs of thinned and unthinned plots. For 5 of the pairs the disparity in total number of trees created by precommercial thinning at age 3 was largely maintained through age 21, resulting in 804 trees per acre on thinned plots and 1,790 trees on unthinned plots. Here, due to good survival in both treatments, the thinning was effective. Thinned plots produced about twice as much merchantable volume as unthinned plots but had only about 45% as many total trees (Figure 1). But, for 4 of the 9 pairs there was a convergence in the number of surviving trees such that by age 21 the total number of trees was 773 per acre on thinned plots and 997 on unthinned plots. The convergence in density, due primarily to natural mortality on the unthinned plots, apparently caused the thinning to be non-effective. Here thinned plots had 78% as many total trees as unthinned plots and produced only 86% as much merchantable volume (Figure 1). Perhaps if the stands had been inventoried at an earlier age before any appreciable mortality had occurred, a significant overall difference in merchantable volumes would have been detected.

Shortleaf volumes are much lower than those of loblolly and slash (Table 3). Most of the overall lower volume performance of shortleaf was due to its particularly poor performance at the St. Regis location. Although survival here was about average, dominant heights were only about 50% as tall, total volume was only 23% as large, and merchantable volume was only 7% as large as the average for those responses for shortleaf at the other two locations. The cause for the poor performance is not known, but apparently this poor, dry, sandy site does not meet nutrient or moisture requirements for good height and volume growth for at least this source of shortleaf pine. Loblolly and slash pine height and volumes were also reduced at this location But less severely. In contrast, By the time of the inventory at age 21, several longleaf pine volunteers had become established in the unthinned shortleaf plot and were 5 inches larger in diameter and 22 ft taller than the shortleaf.

Limited information is available on the response of longleaf to precommercial thinning in this investigation because the thinning treatments were imposed on this species at only the Escambia location at age 5. The information for this location is shown in Table 4 which also includes the data for the unthinned longleaf stands at the Miller and St. Regis locations. At the Escambia location natural mortality, apparently from brownspot and suppression, reduced the total density of the unthinned plot to a level comparable to that of the thinned plot by age 21. The unthinned plot had about 3,230 seedlings and saplings at age 5 (Table 2) which was reduced to

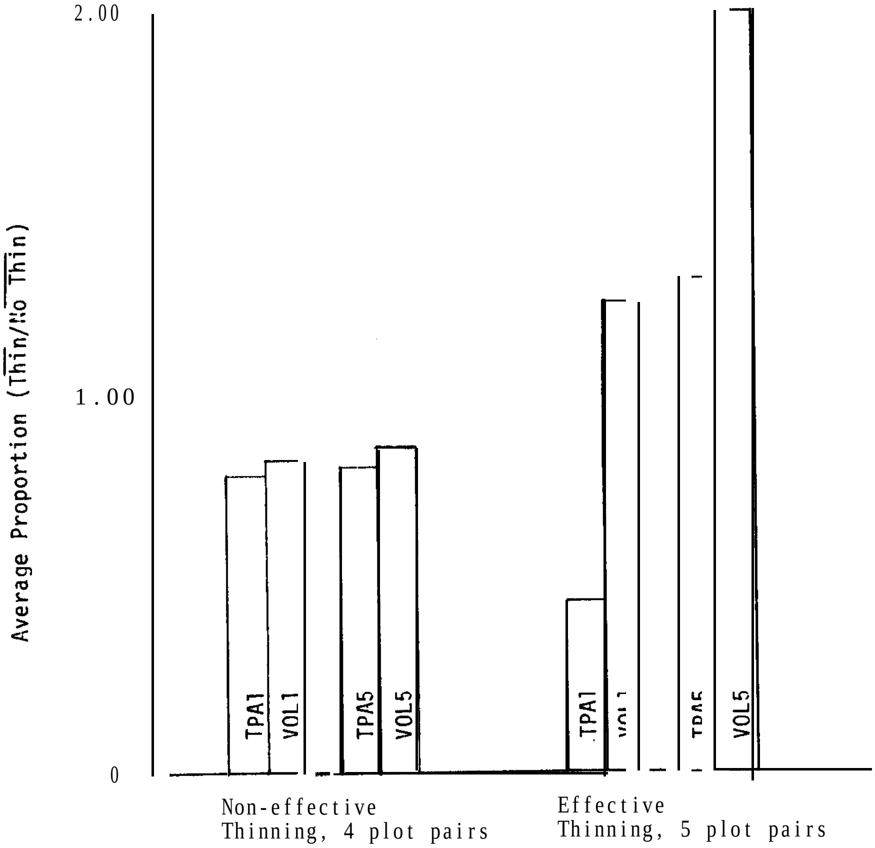

Figure 1.--Effective vs. non-effective preconmercial thinning.

Table 4.--Longleaf response to thinning[1/]

Treatment	DH	TPA1	BA1	DBH1	VOL1	TPA5	BA5	DBH5	VOL5
	ft	no.	ft^2	in.	ft^3	no.	ft^2	in.	ft^3
			ESCAMBIA						
Thin	56.3	540	104	5.9	2,218	376	95	6.8	1,912
No thin	58.5	712	105	5.2	2,292	328	93	7.2	1,978
			MILLER						
No thin	49.3	326	44	5.0	761	136	35	6.8	576
			ST. REGIS						
No thin	46.9	226	37	5.5	657	132	33	6.8	550

[1/] Escambia means based on one g-acre plot per treatment, Miller and St. Regis mean based on two ¼-acre plots per location.

712 trees by age 21, while the thinned plot had about 710 trees at age 5 and 540 at age 21. The result was that both the thinned and unthinned plots produced about the same total and merchantable volumes at age 21. The other responses were also roughly the same.

Longleaf mortality was even more severe at the other two locations. The Miller plots were reduced from about 3,115 stems at age 5 to 326 trees at age 21. The reduction at the St. Regis plot was from about 1,615 stems at age 5 to 226 stems at age 21. These reductions coupled with poorer sites, resulted in the volume production at these two locations being only about 1/3 of that at the Escambia location. Overall, longleaf produced about 1,224 ft3 of average total volume and about 1,024 ft^3 of average merchantable volume (about 12.8 cords). Its volume production appears to be roughly the same as that of shortleaf (Table 3).

These results agree with other observations that longleaf generally has little need for precommercial thinning. However, if young longleaf stands have more than 1,000 stems in active height growth, precommercial thinning should be considered if maximum early merchantable yields are desired (Farrar 1974).

SUMMARY

Precommercial thinning at age 3 in seeded stands of loblolly, shortleaf, and slash pines resulted in significantly fewer total trees and larger mean diameters in the thinned stands at age 21, but no significant difference in total volume occurred. Thinning apparently concentrated the total volume on fewer larger trees. The average difference in merchantable volume between thinned and unthinned stands was not significant but was about 6.6 cords in favor of thinned stands. Also, where thinning was effective (the disparity in total number of trees created by thinning was largely maintained) thinned plots had 45% as many total trees but twice as much merchantable volume as unthinned plots. This suggests that precommercial thinning at age 3 to leave about 700 trees per acre can result in greater merchantable volume production at about age 20 when mortality does not reduce unthinned stand density to a level comparable to thinned stand density.

Overall, loblolly pine was significantly superior in volume production to shortleaf pine. Slash pine volume production was less than loblolly and greater than shortleaf, but the differences were not significant. The average yields were 25.9, 12.5 and 18.0 cords for loblolly, shortleaf and slash pine, respectively.

The limited longleaf data did not indicate any advantage for precommercial thinning in this species. Its overall volume production seemed about the same as that of shortleaf.

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AN EXPERIMENT TO EVALUATE ROW, SELECTION, AND COMBINATION THINNING: DESIGN AND INSTALLATION RESULTS[1]

Robert L. Bailey and Leon V. Pienaar[2]

Abstract.--Row thinning is preferred over selective thinning by many foresters due to the ease and lower costs of harvest operations. However, past silvicultural tests indicate that selective thinning is superior in both volume and value production. A partially balanced incomplete block design was used to develop a study to test row, selective, and row-selective combination thinnings at 50%, 40%, and 33% levels of removal and to generate data for subsequent refinements of growth and yield models. Care was taken to keep type of thinning and level of removal unconfounded in the design. Sixteen replications were installed in site prepared loblolly and slash pine plantations.

INTRODUCTION

As the forest industries of the South and Southeast become more and more dependent on plantations for a source of softwoods, the questions about thinning become more important: Should it be done? When? How? How much should be removed? High quality sawlogs and peeler bolts will be hard to find during rotations of reasonable length without thinning. Furthermore, with stumpage values for solid wood products continuing to increase and often exceeding those for fiber by as much as 5:1 for equivalent volume units (Heist, 1980), the economic incentive to try and answer these questions about thinning is quite obvious. It is also obvious that they are not questions to be answered by biological considerations alone. However, without reliable estimates of volume growth and stem quality for alternative choices, the economically best choice will be difficult to make and the questions will continue to be more a matter for speculation and debate than for analysis.

The choices are almost infinite for questions of how to thin, how much to remove, and when to remove it. They can, however, be narrowed to a few of primary interest by considerations of past work and operational feasibility.

REVIEW OF PAST WORK

Concerning the question of how to thin, past work indicates that row thinning is desirable operationally due to the lower thinning cost per cunit removed and the potential for mechanization of the operation. On the other hand, data from past work (Cremer and Meredith, 1976; Belanger and Brender, 1968) also confirm that selective thinning is superior to row thinning in both volume and value production. A combination of selective and row thinning is appealing as a compromise. This alternative, a combination of row and selective thinninga, has not been adequately tested under controlled, experimental conditions for pines in the South and Southeast.

The question of how much to remove is also an issue which pulls one way then the other. Large volume removals tend to increase net revenues from the thinning operations. However, if the removal is too large, growing stock can be reduced below the most effective level for per-acre production. In stands which averaged 18 CCF[3]/acre

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[3] One CCF = 100 cubic feet of wood to a 2-inch top

at age 13, Keister (1972) reported data showing an increase in total production to age 29 of 12% over unthinned stands when a 23% removal at age 13 and a 25% removal at age 24 had been made. In the same study, a 56% removal at age 13 and a 33% removal at age 26 gave 10% less than the unthinned stand and 20% less than the light thinning. Lighter thinnings also tended to magnify the differences in growth between row thinning and selective thinning in Pinus radiata (Cremer and Meredith, 1976).

The question of how much to remove can easily be confounded with the question of how to do it. Obviously a row thinning removing every' third row should not be compared to a row-selection combination of every third row as well as selection on adjacent rows. The comparison of methods would be completely confused with the concurrent comparison of thinning intensities; (removal = 33%) vs. (removal > 33%).

When to thin, like how much to remove, is a question that also must be viewed in both an economic and biological context. For optimum wood production thinnings should be made just before current annual increment declines sharply. For slash pine plantations this would be age 13 or 14 (see Bennett, 1971). A light thinning, 20-30% removal (3-5 CCF), at this age would tend to forestall significant mortality. The remaining trees would not have to rebuild crowns depleted by crowding as in late thinnings and could continue growing thriftily. Most objections to early thinnings relate to the economics of the operation. If too little volume is remove , the operation could produce negative net revenue. However, this should be considered a silvicultural investment just as fertilization or weeding. If the subsequent payoff in growth of trees with high quality stems is significant, it may be just as sound an investment.

STUDY OBJECTIVES AND DESIGN

The main objective of our study is to test the effects on cubic foot and board foot volume production of 3 types of thinning strategies at 3 levels of residual densities in combination with 2 frequencies of rethinning. The thinning strategies are (a) selective, (b) row, and (c) row-selective combination. Each of these will be tested at residual densities (first thinning) of 50%, 60% and 66% with either no or one repeat thinning. Repeat thinnings will be selective and leave the same percentage of trees as was left in the initial thinning. In addition to the main objective, data from this study will be used to refine the University of Georgia PMRC[4/] yield models for site-prepared plantations.

Table 1 shows the rows removed and combinations of row and selection thinning imposed in achieving the required residual densities at the first thinning. Treatments will be tested against each other and against an unthinned control (T). The RS type thinning was imposed in a way tha? maintains approximately the same selection pressure (34% to 39%) at each residual density level. Data from the study will also be used to estimate the shapes and levels of growth curves (Fig. 1) hypothesized from P. radiata studies (Cremer and Meredith, 1976). The hypothesis is that light thinnings are more desirable for total growth and that the difference between R and S thinnings is greater for light thinnings.

[4/] The Plantation Management Research Cooperative with 13 participating companies was organized in 1976 to develop management information for site-prepared plantations.

Table 1.--Rows to remove and percent selectivity[1/] for combinations of thinning types and residual densities.

Thinning Type	Thinning Intensity (trees per acre) 50%	40%	33%
1. Selective thinning (S)			
a) Rows removed	none	none	none
b) Percent selectivity[1/]	100	100	100
2. Row thinning (R)			
a) Rows removed	2nd	2nd & 5th	3ra
b) Percent selectivity	0	0	0
3. Row-selective thinning (RS)			
a) Rows removed	3rd	4th	5th
b) Percent selectivity	34	37.5	39

[1/] Percent selectivity $= 100\left[\frac{\text{percent removed by selection}}{\text{total percent removed}}\right]$

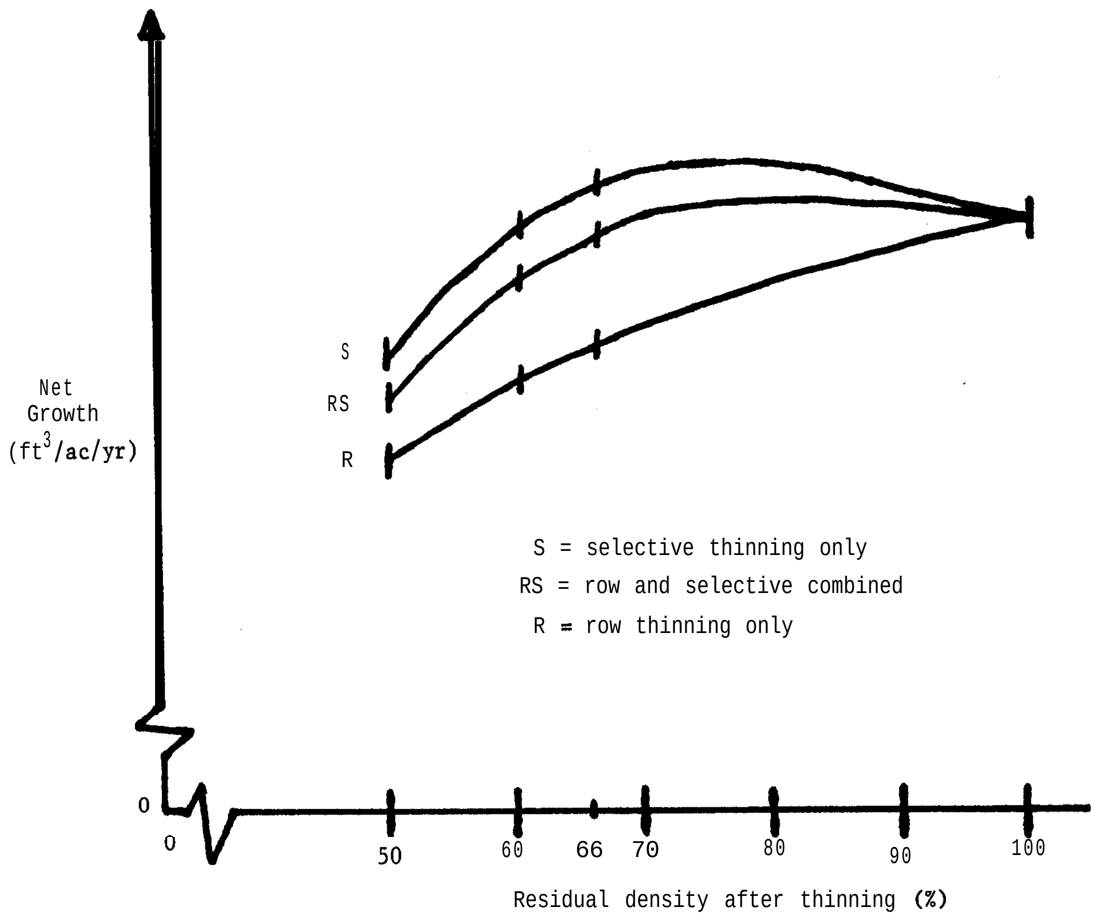

Figure 1. --Hypothesized relative response curves based on *Pinus radiata* in Australia.

For designing the field plot and treatment layout, the treatments or factors are:

1) Factor A Thinning Repetitions

Level	Description
0	Thin only once (T_1)
1	Thin twice, 8 year delay (T_2)

2) Factor B Thinning Type

Level	Description
0	Selective thinning (S)
1	Row thinning (R)
2	Row-selective combination (RS)

3) Factor C Residuah Densities (trees per acre)

Level	Description
0	50%
1	60%
2	66%

The selective thinnings after 8 years will leave the same percentage of trees as the initial thinning. For example, suppose a plantation had 700 trees per acre prior to the first thinning. If the treatment was C_1 (60fresidual density), 420 trees would be left. The same stand with 418 trees eight years later, if repeat thinning was performed, would be left with 251 after thinning.

The treatments were arranged in factorial combinations in incomplete blocks of 10 plots each counting one unthinned plot per block. One complete replication of the study requires 2 blocks. This design will give complete, although unbalanced, data on the main factors and all two-factor interactions unconfounded with blocks. The three-factor interaction (4 degrees of freedom) is partially confounded with blocks which means only limited information on this effect will be derived from the study. However, for a 47% reduction in numbers of plots as compared to a complete-block design, we felt this sacrifice of information was justified.

Plans called for the study to be balanced, as nearly as possible, over two age classes for both slash (*Pinus elliottii*) and loblolly (*Pinus taeda*) pine plantations on site-prepared areas. Groups for age of first thinning are 13 to 15 and 16 to 18 years. Only plantations with ,500 to 700 trees per acre at these ages were selected.

After two summers of field work the basic design has been installed at 16 locations:

	Age Group	
Species	13-15	16-18
	(no. replications)	
Loblolly	6	5
Slash	3	2

All treatment plots are approximately ½ acre with adjustments as necessary to obtain a whole multiple of the appropriate numbers of rows where row thinning was the treatment. Each measurement plot was centered as nearly as possible in a treatment plot and are approximately ¼ acre. Diameters of all trees and heights of 25% of the trees were measured at plot installation. Trees to remain after thinning were tagged with numbered, aluminum tags. Each tree was given a code for "potential sawtimber" or "not potential sawtimber" based on a subjective evaluation of stem crook and sweep and the presence or absence of fusiforme cankers. The reason for "not potential sawtimber" was also recorded when that was the class assigned.

We had hoped for summaries of the before- and after-thinning data at this meeting, but our data are still being keypunched and checked for errors. Therefore, we look forward to reporting on the thinning results and the analysis of growth following thinning at subsequent meetings.

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GUIDES FOR THINNING SHORTLEAF PINE [1]

Robert Rogers [2]

Abstract .--Growing-space requirements of shortleaf pines are defined and used to guide thinning. The growing-space concept is used to develop stocking charts, suitable for both crop tree release and area thinning. An on-the-ground method is developed for crop tree selection. These techniques can be applied to thin shortleaf pine stands in order to increase or maintain diameter growth.

Providing practical information on when and how to thin stands of any species requires knowing the species' growing space requirements. Foresters commonly describe growing space requirements by measuring crowding or density within stands. Two frequently used measures of density are basal area and numbers of trees. These two measures can be further used to calculate mean stand diameter. Together, the three descriptors provide a better index of how fully a site is occupied with trees than any one descriptor can provide.

Stocking charts depict graphically the relation among these stand density measures 'and average stand diameter so that measured density can easily be compared to standards or norms of stand density. Stocking charts depict density standards in a way that can be used to meet management objectives, such as maximizing growth and regenerating the stand.

Stand density does not remain constant. As trees grow and average stand diameter increases, stand basal area increases and tree numbers decrease. Tree numbers decline with time because trees compete for limited resources. All trees share the site's resources, but not equally. Large trees demand and receive proportionately more resources than small trees do. Individual trees thus remain in continuous and precarious balance with available resources. Consequently, as stands grow, some trees fail to receive the minimum resources needed for survival . Although competition reduces tree numbers, survivors still grow slowly.

If growing trees to large diameters quickly is an important management goal, then we need to thin stands because "natural thinning" is too slow. When cultural thinnings are made, resources are freed and become available to remaining trees. Consequently, growth is concentrated on fewer trees, thereby shortening the time needed to produce large diameter trees.

We can develop guides for thinning shortleaf pine stands based on the concepts that: (1) the resources on a site are fixed, (2) these resources are shared by individual trees, (3) large trees use more resources for growth than small trees do, and (4) there is a maximum amount of resources that trees can use.

Guides developed here are based on the minimum and maximum resources needed for shortleaf pine growth. The term "growing space" is used to express the idea that a tree's resource needs can be expressed as an area of ground.

We can measure growing space by equating it to a tree's crown area projected onto the ground. Moreover, the crown cross-sectional area of an open-grown tree (competition free) can be used to represent maximum growing space. Crown areas can be calculated using crown diameter measurements. But unfortunately, crown diameters are not easily measured in the field. However, knowing the relation between crown diameter and an easily measured, but highly correlated, tree attribute such as d.b.h., would allow us to predict the maximum growing space requirements of trees of any d.b.h.

The growing space concept also conveniently expresses the idea that the space available to a tree largely determines its growth. However, there is an upper limit to the amount of growing space a tree can use. Providing a tree with maximum growing space results in maximum growth.

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The value for maximum growing space also establishes the minimum number of trees of a given mean d.b.h. that can fully utilize any given amount of area.

In addition to knowing this maximum spatial requirement, we also should know the minimum space necessary for a tree to survive. This quantity can then be used to define a standard for "minimum growing space." This spatial requirement can be obtained by using the tree area ratio equation (Chisman and Schumacher 1940) and data collected from natural undisturbed stands.

Accordingly, I used the estimated maximum and minimum growing spaces of shortleaf pine to develop a stocking chart by following the techniques used on upland hardwoods by Krajicek et al. (1961) and Gingrich (1967). Similar guides are available for northern hardwoods (Leak et al. 1969), paper birch (Marquis et al. 1969), spruce-fir (Frank and Blorkbom 1973), white pine (Philbrook et al. 1972), jack pine (Benzie 1977), red pine (Benzie 1977), black walnut (Schlesinger and Funk 1977), and Allegheny hardwoods (Roach 1977).

CROWN DIAMETER STEM DIAMETER RELATIONS

METHODS

Maximum Growing Space Requirements

I measured crown and stem diameters on 141 open-grown shortleaf pines in five southeastern Missouri counties. Sample trees had: (1) lowest branches as long or longer than those above, (2) no evidence of pruning, shearing, browsing, decadence, storm damage, or serious insect damage, and (3) historical evidence obtained from local residents that the tree was of seedling origin and always open-grown. Suitable trees were found in cemeteries, wooded pastures, parks, and road rights-of-way.

Crown diameter of each tree was measured twice, the second measurement at right angles to the first, and the results were averaged. The location of each crown edge was estimated ocularly and a perpendicular line was projected from the crown edge to the ground. Then the distance between the projected crown edges was measured to the nearest one-tenth of a foot with a tape.

I made no attempt to determine either site index or age. The crown-stem relation in other species is apparently independent of these factors (Krajicek, et al. 1961; Gingrich 1967).

Bartlett's three group method for model II regression (Sokal and Rohlf 1969, pp. 481-486) was used to estimate the coefficients in the linear model

$$CD = a + bDBH \tag{1}$$

where CD = crown diameter (ft)
DBH = Stem d.b.h. (in)
a, b = coefficients

I used Bartlett's method to estimate coefficients because the independent and the dependent variables were subject to random error that made using the usual least squares method inappropriate.

Crown area (CA) (mllacres) of open-grown trees was derived from the relation

$$CA = \frac{\pi CD}{(4)(43.56)} \tag{2}$$

where CD is crown diameter (feet)

When equation (1) is substituted for CD in equation (2) and the terms are expanded and the coefficients are redefined, equation (2) becomes

$$CA = a + bDBH + cDBH^2 \tag{3}$$

Thus, equation (3) defines the crown area and therefore the maximum growing space, G_{max}, of an open-grown tree of any d.b.h.

Minimum Growing Space Requirements

Equation (3) has the same form as the tree-area ratio equation used by Chisman and Schumacher (1940) and later by Gingrich (1967) to develop minimum growing space requirements (G_{min}) of trees. However in this case, data collected from natural undisturbed stands representing a range of ages and sites are normally used to determine coefficents of the tree-area ratio equation. Consequently, the two equations differ only by the values of their coefficients. Natural undisturbed stands are difficult, if not impossible, to find in southeastern Missouri, Arkansas, and surrounding states. As an alternative to field data, I considered and then rejected using published data to determine the requirement for minimum growing space. I decided not to use the shortleaf pine data in Table 168 of USDA Publication 50 (1976) because these data indicated that stand basal area quickly reached a plateau at an average stand diameter of 7 inches. Besides seeming unreasonable, stand basal area of other southern pines, red pine, and white pine continues to increase as average stand diameter increases. In addition, neither a Missouri nor a West Gulf Region study of shortleaf pine indicated that stand basal area remains constant as stand diameter increases beyond 7 inches (Sander and Rogers 1979, Murphy and Beltz 1981). However, Smalley and Bailey (1974) showed that stand basal area peaks and then remains constant or even declines in some unthinned shortleaf pine plantations growing on abandoned fields of the Interior Highlands of Tennessee, Alabama, and Georgia.

Because of the difficulty in locating suitable stands to measure and conflicting published information, I decided not to use actual stand data and the tree-area ratio equation to define minimum growing space requirements. Instead, I defined minimum growing space as 60 percent of maximum growing space. This approximation is consistent with Roach's (1977) findings that minimum growing space for full site utilization of most species is between 50 and 70 percent of maximum growing space. Thus $G_{min} = 0.6*G_{max}$.

RESULTS

The relation between crown diameter and d.b.h. was highly significant ($p < .01$). The prediction equation is

$$CD = 2.852 + 1.529\ DBH;\ r2 = 0.92;$$

$$s_{y.x} = 2.931 \quad (4)$$

The equation describing maximum growing space is

$$G_{max} = 0.147N + 0.157\Sigma DBH + 0.042\Sigma DBH^2 \quad (5)$$

And the equation describing minimum growing space is

$$G_{min} = 0.088N + 0.094\Sigma DBH + 0.025\Sigma DBH^2 \quad (6)$$

where N = number of trees and G is in milacres.

Maximum and minimum tree area requirements of single trees by diameter class are obtained by setting N = 1 in equations 5 and 6 (Table 1). Metric equivalents are presented in Table 2. These two requirements define the limits within which growing space is fully utilized.

Table 1.--Relation between tree d.b.h., basal area, and tree area requirements

D.b.h. (inches)	Basal area (square feet)	Tree area requirements: Maximum 1/ (milacres)	Minimum 2/ (milacres)
2	0.022	0.63	0.38
4	0.087	1.45	0.87
6	0.196	2.61	1.56
8	0.349	4.10	2.46
10	0.545	5.94	3.56
12	0.785	8.10	4.86
14	1.069	10.61	6.37
16	1.396	13.46	8.07
18	1.767	16.64	9.98
20	2.182	20.16	12.09

1/ Maximum tree area = $.14663 + .15726DBH + .04216DBH^2$

2/ Minimum tree area = $.08798 + .09435DBH + .02530DBH^2$

STOCKING CHART

To calculate percent relative density we need the following stand data: number of trees per acre, the sum of diameters, and the sum of diameters squared. We can easily obtain number of trees and basal area per acre from field measurements. Because $DBH^2 = BA/.005454$, equation (6) for minimum growing space can be rewritten as

$$G_{min} = 0.088N + 0.094\ \Sigma DBH + 4.584BA \quad (7)$$

Unfortunately, the sum of diameters is not easily obtained from field measurements. The job is less tedious if we use point sampling procedures and measure the d.b.h.'s of sample trees. Then percent relative density can be calculated by summing the percent relative density contributed by each sample tree. The equation we need to find the amount contributed by each tree is derived by combining the minimum growing space equation (7) with an estimate of the number of trees a point sample tree represents, which is $N = BAF/(.005454DBH^2)$. Then

$$\text{Percent contribution} = \left\{0.088\left[\frac{BAF}{.005454DBH^2}\right] + .094\left[\frac{BAF}{.005454DBH^2}\right]DBH + 4.584\left[\frac{BAF}{.005454DBH^2}\right].005454DBH^2\right\} \div 10 = BAF\left[\frac{1.613}{D^2} + \frac{1.723}{D} + 0.458\right] \quad (8)$$

where D is d.b.h. (inches) of sample tree and and BAF is basal area factor (BAF) of the wedge prism.

The metric equation can be derived similarly and results in

$$\text{Percent contribution} = BAF\left[\frac{45.33}{D^2} + \frac{19.14}{D} + 2.02\right] \quad (9)$$

where D is measured in cm and BAF is in meters per hectare. The solution of equation (8) and (9) is shown in Table 3.

Alternatively, we can eliminate the need to measure tree diameters altogether by constructing a stocking chart that has a "built in" typical d.b.h. distribution, and we can use the stocking chart to approximate percent relative density. Because I had few suitable stand data to estimate average stand structure of shortleaf pine, I borrowed Gingrich's (1967) data on upland hardwoods, Upland hardwood and shortleaf pine'stand structures tend to be similar. Like the upland hardwoods, shortleaf stands are even-aged and develop a near normal, but at times wide-spread, diameter frequency distribution. The coefficient of variation of mean d.b.h. in hardwood stands is inversely related to quadratic mean diameter (QSD) and varies from 0.45 to 0.29 as QSD increases from 3 to 15 inches (Gingrich 1967). The stocking charts for shortleaf pine, figures 1 and 2, are based on these hardwood coefficients of variation.

Table 2.--Relation between tree d.b.h., basal area, and tree area requirements

D.b.h. (cms)	Basal area (square dms)	Tree area requirements: Maximum 1/ (ares)	Minimum 2/ (ares)
6	0.283	0.0305	0.0183
10	0.785	0.0574	0.0345
14	1.539	0.0928	0.0557
18	2.545	0.1367	0.0820
22	3.801	0.1891	0.1134
26	5.309	0.2499	0.1499
30	7.069	0.3191	0.1915
34	9.079	0.3968	0.2381
38	11.341	0.4830	0.2898
42	13.854	0.5777	0.3466
46	16.619	0.6808	0.4085
50	19.635	0.7924	0.4754
54	22.902	0.9124	0.5474
58	26.421	1.0409	0.6245
62	30.191	1.1779	0.7067
66	34.212	1.3233	0.7940
70	38.485	1.4772	0.8863
74	43.008	1.6396	0.9837

1/ Maximum tree area = $(5.93405 + 2.50548DBH + .26447DBH^2)/1000$

2/ Minimum tree area = $(3.56043 + 1.50329DBH + .15868DBH^2)/1000$

Table 3 .--Contribution to percent relative density made by point sample trees of different d.b.h.s given BAF of 10 ft^2/acre and $2m^2$/hectare

D.b.h.	BAF = 10 ft^2/acre relative density contribution	D.b.h.	BAF = $2m^2$/hectare relative density contribution
Inches	Percent	Centimeters	Percent
1	38	2	46
2	17	3	27
3	12	4	19
4	10	5	15
5	9	6	13
6	8	7	11
7-9	7	8	10
10-19	6	9-10	9
2ot	5	11-13	8
		14-17	7
		18-28	6
		29+	5

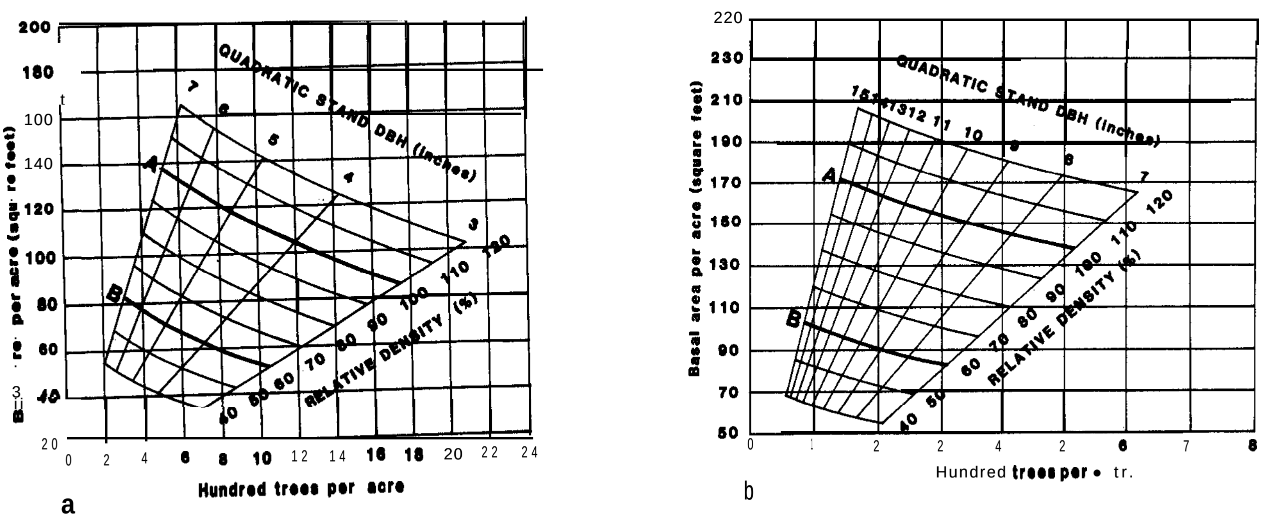

Figure 1.--Relation of basal area, number of trees, and average tree diameter to percent relative density for shortleaf pine (English units). Tree diameters range from 3-7 inches in figure la and from 7-15 inches in figure lb. The area between curves A end B on both charts indicates the range in relative density where trees can fully utilize available growing space. (Average tree diameter is the diameter of the tree of average basal area).

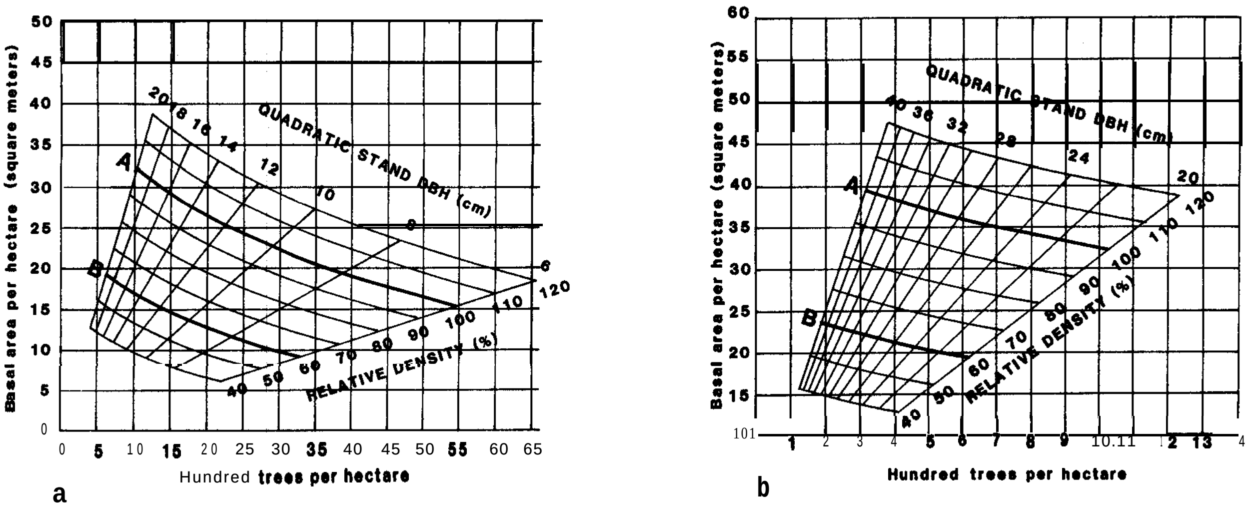

Figure 2.--Relation of basal area, number of trees, and average tree diameter to percent relative density for shortleaf pine (metric units). Tree diameters range from 6-20 cm in figure 2a and from 20-40 cm in figure 2b. The area between curves A and B on both charts indicates the range in relative density where trees can fully utilize available growing space. (Average tree diameter is diameter of the tree of average basal area.)

I constructed the stocking chart using equation (6) to solve for N and BA as I varied quadratic mean stand diameter and percent relative density. My first step was to divide (6) by 10 to put it on a percentage basis:

$$\text{percent relative density (PRD)} = 0.88N + 0.94\,\Sigma DBH + 0.25\,\Sigma DBH^2 \qquad (10)$$

then factoring N from the right hand side of equation (10) gives:

$$PRD = N\left[0.88 + 0.94\,\frac{\Sigma DBH}{N} + 0.25\,\frac{\Sigma DBH^2}{N}\right]; \qquad (11)$$

and rearranging equation (11) to solve for N gives:

$$N = \frac{PRD}{0.88 + 0.94\,\frac{\Sigma DBH}{N} + 0.25\,\frac{\Sigma DBH^2}{N}} \qquad (12)$$

Note that $\frac{\Sigma DBH}{N}$ equals arithmetic mean stand diameter (ASD) and $\frac{\Sigma DBH^2}{N}$ equals quadratic mean stand diameter squared (QSD^2). QSD is related to ASD by the coefficient of variation of ASD

$$QSD = ASD\sqrt{1 + CV^2}. \qquad (13)$$

Expressing ASD in terms of QSD gives:

$$ASD = \frac{QSD}{\sqrt{1 + CV^2}}. \qquad (14)$$

Substituting $\frac{QSD}{\sqrt{1 + CV^2}}$ in equation (12) results in

$$N = \frac{PRD}{0.88 + 0.94\,\frac{QSD}{\sqrt{1 + CV^2}} + 0.25QSD^2} \qquad (15)$$

Because I wanted CV^2 to also be expressed in terms of QSD, I used linear regression and Gingrich's (1967) data to calculate CV from QSD. The resulting equation was:

$$CV = 0.484 - 0.01275QSD;\ r^2 = 0.996,\quad s_{y.x} = 0.0033; \qquad (16)$$

then (17)

$$N = \frac{PRD}{0.88 + 0.94\,\frac{QSD}{\sqrt{1+(0.484-.01275QSD)^2}} + 0.25QSD}$$

and

$$BA = N\ .\ QSD. \qquad (18)$$

The metric stocking chart was constructed in the same way. These charts can be used to estimate relative density in shortleaf pine stands if two of the following quantities are known: number of trees, basal area, or quadratic mean stand diameter.

The charts overestimate percent relative density in stands whose diameter range is narrow and underestimate those with a wide range. For maximum accuracy in estimating percent relative density, tree diameters should be measured and percent relative density should be calculated by using equation (6) or (7).

Roach and Gingrich (1968) give a good account of estimating basal area measurements, and Rogers (1980) presents the same information for metric measurements. In practice, trees 3 inches d.b.h. or smaller, if present at all, can be ignored in sawtimber stands. But Z-inch trees should be counted in stands composed of pole-sized trees. In all other stands, trees l-inch d.b.h. or larger should be counted. Understory trees and shrubs should not be counted.

Percent relative density in mixed pine-upland hardwood stands can be estimated by tallying pine and hardwood basal areas and numbers of trees separately. Then the pine stocking chart (fig. l-2) can be used to estimate the percent relative density of pine, and the upland hardwood stocking chart (Gingrich 1967) can be used to estimate the percent relative density (percent stocking) of the upland hardwoods. Percent relative density of the mixed stand is then the combined percent relative densities of the hardwood and pine.

Application of the Stocking Chart

Now that we have a stocking chart, what can we use it for? I have designated two reference lines on the stocking chart. One line (B) defines the minimum tree density for full site utilization, and the other (A) defines maximum density for full site utilization. When densities fall below the minimum density, trees have more room on the average than they need for maximum growth. If stand densities are above the maximum, the trees are too dense to maintain adequate growth and therefore mortality increases substantially.

To maximize the growth of both trees and stands, we need to have stands at a density that provides the average tree with no more or less than the maximum amount of growing space it can use. Theoretically this condition results in no wasted space. But in reality, the growth of each tree in a stand is not usually at a maximum because growing space is calculated as an average stand condition that does not necessarily pertain to each individual tree. To realize maximum d.b.h. growth per tree, each tree must be allocated its specific growing space based on its diameter. So thinning procedures must not only achieve a relative density goal on an area-wide basis, but must strive to furnish each tree with its maximum growing-space requirements.

To thin shortleaf pine stands, we need to set a stocking goal for each stand or group of stands . If timber production is important to us, we need to know when to expect a yield of merchantable products from our stands. For example, if saw logs bigger than 15 inches d.b.h. are the only products we expect from a stand currently 10 years old, then we should provide maximum growing space for only those crop trees that will be present at the end of the rotation. How many crop trees are necessary is determined by our goals of what future average d.b.h. and percent relative density should be.

On the other hand, if intermediate thinnings are profitable, then we can provide maximum growing space for all trees at the outset of our thinning program. A prudent thinning strategy is one that delays providing maximum growing space for all trees in a stand until thinning becomes profitable. If we know this point in time, then stocking goals can be defined and thinning procedures can be adjusted to agree with our goals. But most importantly, each crop tree must be provided with its specific maximum growing space.

After we have decided on our management goal and determined a future average stand diameter and percent relative density, we can use the stocking chart to find the corresponding number of future crop trees. Assuming that we want each of these future crop trees to have all the growing space they can use (60 percent relative density), we must remove other trees that compete with their growing space.

Distance between crop trees can be calculated by dividing the number of trees needed into 43,560 ft^2 (acre) or 10,000 m^2 (hectare) and taking the square root of the result. The forester should choose crop trees with desirable characteristics nearest the spacing just calculated along straight lines projected within the stand. Neighboring trees should be cut if they are closer than

$$1.322 + 0.709 DBH(in) \quad \text{feet} \tag{19}$$

$$0.403 + 0.085\ DBH(cm) \quad \text{meters} \tag{20}$$

where DBH is the diameter of the larger tree. A simple thinning rule can be used to approximate this distance in feet by multiplying DBH by 7, dividing by 10, and adding 1.3 feet, i.e., distance (feet) = (7*DBH)/10 + 1.3; or In meters, distance (meters) = DBH/10 + 0.4.

I developed these equations from equation (4), which predicts crown diameter given d.b.h. Initially, thinning radii were calculated by dividing equation (4) by 2.

$$\text{thinning radius} = 1.426 + 0.7645DBH \qquad (21)$$

But computer simulations of thinnings in stands showed that percent relative density was being reduced below the desired 60-percent level by using this thinning radius. By experimenting, I found that reducing the thinning radius given in equation (21) by 7.3 percent was necessary to thin stands to 60 percent relative density. This led to equations (19) and (20). Thinning radii based on these equations for trees of different diameters are given in Table 4.

Table 4 .--Thinning radii associated with shortleaf pine of varying d.b.h.s

D.b.h.		Radius	
Inches	Centimeters	Feet	Meters
3	7.6	3	1.1
4	10.2	4	1.3
5	12.7	5	1.5
6	15.2	6	1.7
7	17.8	6	1.9
8	20.3	7	2.1
9	22.9	8	2.3
10	25.4	8	2.6
11	27.9	9	2.8
12	30.5	10	3.0
13	33.0	11	3.2
14	35.6	11	3.4
15	38.1	12	3.6
16	40.6	13	3.9
17	43.2	13	4.1
18	45.7	14	4.3
19	48.3	15	4.5
20	50.8	16	4.7

Using this thinning method for all trees ensures, within the confines of preexisting spatial pattern, that each tree and the stand will be as close to 60 percent density as possible. But if only crop trees are considered, only they can be assured of having sufficient space for maximum growth.

My experience with shortleaf pine stands in Missouri shows that percent relative density increases from 2 to 4 percent per year. The rate is higher in young stands and those on good sites; it is lower for old stands and stands on poor sites. On a conservative basis, a stand thinned to 60 percent relative density will be at 80 percent relative density in 10 years, and at 100 percent relative density in 20 years. As percent relative density increases, growth on individual trees decreases, so a balance must be struck between diameter growth and frequency of thinnings. If thinnings are delayed much beyond a recommended 10-year interval, diameter growth of remaining trees will be reduced substantially. Moreover, a IO-year thinning cycle maintains steady, near maximum growth on residual trees.

In some instances, percent relative densities other than 60 percent will be desirable. For example, reducing percent relative density to 50 or 40 percent encourages pine regeneration which thrives under these low overstory density conditions as long as hardwood competition is controlled.

Guides for thinning shortleaf pine involve setting management goals, using stocking charts to determine future density levels, and using the 7/10 DBH + 1.3 thinning rule. Using these guides will help foresters create favorable growing conditions for all crop trees under their care.

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RECOVERY OF UNDERSTOCKED, UNEVEN-AGED PINE STANDS AND SUPPRESSED TREES[1/]

B. F. McLemore [2/]

Abstract.--Preliminary data indicates that recovery of understocked loblolly-shortleaf pine stands is rapid. Annual increase in percent stocking averaged 4.6 percent during the first two years, while basal area increased approximately 15 percent annually, following logging and release from hardwood competition. Suppressed trees also made good rates of recovery when released, averaging 0.7 inch increase in d.b.h. over the initial Z-year period. The best predictors of a suppressed tree's ability to recover and grow were: (1) stem diameter at the base of the crown, (2) radial growth for 5 years preceding release, (3) d.b.h., and (4) reciprocal of age.

INTRODUCTION

Research at Crossett, Arkansas, shows that uneven-aged management of loblolly (*Pinus taeda*) - shortleaf (*P. echinata*) stands may suit the private nonindustrial landowner's objectives better than intensive even-aged management practiced by most Federal, State, and industrial land managers (Reynolds 1969). A major problem in placing private land under management is the poor condition, or low stocking levels, often found on this land. Marketable stands of sawtimber are often liquidated, leaving the area poorly stocked.

Research on the Crossett Experimental Forest has demonstrated that forest properties having as little as 35 ft^2 basal area, or 2,000 bd. ft/acre (Doyle) sawlog volume can be quickly rehabilitated (Reynolds 1969). But many private ownerships today have stands with stocking levels below 35 ft^2 basal area or 2,000 bd. ft/acre. The question arises then about how poorly stocked a stand may be and subsequently recover after being placed under management. Also, many of the trees left after sawtimber has been cut are intermediate or suppressed, and their ability to recover and make acceptable crop trees is unknown. A series of studies was installed in southern Arkansas in 1979 to provide answers to these questions.

METHODS

Determination of Minimum Stocking Levels

Two uneven-aged loblolly-shortleaf pine-hardwood areas in south Arkansas were selected for study establishment. One study was established in Ashley County, where the site index for loblolly pine is about 95 feet at age 50, hereafter referred to as the good site. A second study was installed in Nevada and Ouachita counties where the site index for loblolly is about 80 feet, obviously the poor site.

Stocking levels of 10, 20, 30, 40 and 50 percent were established on good and poor sites according to the tree-area ratio (Chisman and Schumacher 1940) as modified by McLemore (1981). Treatment plots were l-acre square plots with interior one-half acre measurement plots. The d.b.h. of all trees in the measurement plot was measured after two growing seasons; giving a preliminary rate of recovery. Rate of recovery was evaluated only for those trees which existed at the start of the growth period; new regeneration was excluded from these analyses. All five treatments were replicated three times on each area.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Stocking levels were achieved following a preliminary inventory of the study areas. All trees larger than 12 inches d.b.h. were logged from plots during the winter of 1979-1980. Trees in the smaller d.b.h. classes were subsequently removed until the prescribed stocking levels were attained. Remaining trees ranging from seedlings to 12 inches d.b.h. were selected for uniformity of distribution. An effort was made to select adequate numbers of stems in each l-inch class to approximate a Q factor of 1.2 to 1.3, where Q is the number of trees in a given diameter class as a proportion of the number of trees in the next higher class. Hardwoods on the study plots were injected with Tordon 101 in the spring of 1980.

Recovery of Suppressed Trees

Eighty-two intermediate and suppressed loblolly pines were selected on the isolation strips of the good site described above. The following 10 variables were measured for each tree to determine most important factors in predicting the ability of a suppressed tree to recover following release: (1) height, (2) d.b.h., (3) age, (4) radial growth last 5 years, (5) crown volume, (6) percent live crown, (7) stem diameter at base of crown, (8) hardwood competition index prior to release (Daniels and Burkhart 1975), (9) pine competition index prior to release, and (10) pine competition index after release. No measurements were made of the hardwood competition index after release since all hardwoods were injected when the study was installed. Trees ranged from 2 to 9 inches d.b.h. and from 12 to 43 years of age.

Response of the trees to release was evaluated by measuring d.b.h. after two growing seasons. Stepwise regression analyses were employed to determine the influence of the ten factors listed above on d.b.h. growth.

RESULTS

Stocking Levels

The percentage increase in stocking levels on the good site ranged from 7.2 to 12.5, and averaged 9.5 percent after two growing seasons (Table 1). Percentage increases on the poor site were similar to the good site, ranging from 8.3 to 10.2 and averaging 9.1 percent. Analyses of variance indicated no significant differences in percentage increase in stocking between treatments at either site. Hence, the annual rate of recovery during the initial 2-year period may be considered about 4.6 percent, when new reproduction is ignored. The ingrowth of new regeneration would obviously increase this figure.

Assuming an annual recovery rate of 4.6 percent, the following tabulation indicates the approximate number of years for the various initial stocking levels to reach an acceptable level of 60 percent:

Initial percent stocking	Years to attain 60 percent stocking
10	40
20	25
30	16
40	9
50	4

It is emphasized that this assumes a straight line of recovery at 4.6 percent per year, which may not be the case in future years, and ignores the contribution of new reproduction.

All treatments showed a dramatic increase in basal area over the 2-year period (Table 2). Initial basal areas ranged from about 4 ft^2/acre for the 10 percent stocking level to about 16 ft^2/acre for the 50 percent level. The percentage increase over the two-year period was 38 percent on the good site and 31 percent on the poor site. The basal area of these understocked stands would double in 5 years if an annual increase of 15 percent is assumed.

Recovery of Suppressed Trees

Diameter growth of study trees was surprisingly good during the two years immediately following release. Average d.b.h. increased by 0.7 inch for the 82 trees. Since the trees averaged 4.8 inches d.b.h. initially, an increase in basal area of slightly over 30 percent during the 2-year period occurred. This is even more dramatic when it is considered that the trees averaged 26 years of age when the study was installed.

Table 3 lists the order in which the 10 variables appeared when a stepwise repression for d.b.h. growth was applied. The R2 values are also listed. It is somewhat surprising that diameter at base of live crown appeared first, while percent live crown was last. Little was gained by going beyond the four variables of diameter at base of live crown, radial growth last 5 years, initial d.b.h., and reciprocal of age. The R2 for these four variables was 0.60. None of the competition indices were of any great importance in determining a tree's ability to recover and grow. Again, these are preliminary results, after only two years of observation.

Table 1.--Change in stocking over a Z-year period.

Stocking Percent[1/]			Percent Increase
Initial (1979)	After 2 years (1981)	Change	
		Good Site	
10.07	10.80	0.73	7.2
20.05	21.95	1.90	9.5
30.04	32.67	2.63	8.8
40.11	43.94	3.83	9.5
50.09	56.35	6.26	12.5
		Average	9.5
		Poor Site	
10.33	11.37	1.04	10.1
20.21	22.28	2.07	10.2
30.32	32.84	2.52	8.3
40.48	43.88	3.40	8.4
50.08	54.30	4.22	8.4
		Average	9.1

1/ Based on stocking equation.

Table 2.--Change in basal area over a Z-year period

Percent Stocking	Basal Area (ft^2)			Percent Increase
	Initial (1979)	After 2 years (1981)	Change	
			Good Site	
10	4.03	4.98	0.95	23.6 a [1/]
20	6.96	9.36	2.40	34.5 b
30	9.88	13.18	3.30	33.4 ab
40	11.03	15.68	4.65	42.2 bc
50	12.85	20.07	7.22	56.2 c
			Average	38.0
			Poor Site	
10	4.42	5.76	1.34	30.3
20	7.46	10.05	2.59	34.7
30	11.99	15.74	3.75	31.3
40	13.96	18.34	4.38	31.4
50	17.91	22.94	5.03	28.1
			Average	31.2

1/ Percentages with the same letter do not differ significantly at The 0.05 level.

Table 3.--Regression models for d.b.h. growth after two years.

No. variables in model	R2	Variables in model[1/]
1	0.448	7
2	.533	7, 4
3	.569	7, 4, 2
4	.599	7, 4, 2, 3
5	.607	7, 4, 2, 3, 9
6	.612	7, 4, 2, 3, 9, 8
7	.619	7, 4, 2, 3, 9, 8, 5
8	.622	7, 4, 2, 3, 9, 8, 5, 1
9	.622	7, 4, 2, 3, 9, 8, 5, 1, 10
10	.622	7, 4, 2, 3, 9, 8, 5, 1, 10, 6

[1/]
1. Height
2. Initial d.b.h.
3. Reciprocal of age
4. Radial growth last 5 yrs.
5. Crown volume
6. Percent live crown
7. Diameter at base of crown
8. Hdwd. competition index before release
9. Pine comp. index before release
10. Pine comp. index after release

SUMMARY AND CONCLUSIONS

Results from these studies indicate that understocked, uneven-aged loblolly-shortleaf pine stands may be expected to show an initial annual rate of recovery of 4.5 to 5 percent when hardwoods are controlled. If this trend continues, and new reproduction is ignored, stocking levels will double in approximately 15 years. Annual basal area increase averaged about 15 percent, indicating that basal area will double in 5 years.

Suppressed trees showed good ability to recover and grow following release, averaging 0.7 inch increase in d.b.h. over the initial 2-year period. The most accurate predictors of a tree's ability to recover and grow were stem diameter at the base of the crown, radial growth for 5 years preceding release, d.b.h., and reciprocal of age.

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THINNING THE UPLAND HARDWOOD FOREST: A MECHANIZED SYSTEM[1/]

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Abstract .-In the recent past, many upland hardwood forest stands have been harvested with little thought given to the future stand or it's management. As a result, the growth rate and perhaps quality of future crop trees in such stands could be substantially improved by the selective removal of sub-sawlog size stems. lb date, only a limited number of these stands have been thinned, primarily because harvesting costs exceeded the value of the products removed. Markets have been limited mainly to pulp, but increasing costs and demand for wood biomass may increase the value of wood chips and improve the opportunity for thinning. This paper reports on the costs and productivity of various machines combined to produce a low capital cost but highly mechanized system for thinning upland hardwoods for energy biomass or pulp chips. The system was composed of an 18 inch capacity feller-buncher, a two-wheel-drive grapple skidder, and a 12 inch capacity whole tree chipper. The oak-hickory stand selected for thinning was typical of the region. Depending on the block samples, the basal area ranged from 61 to 105 square feet par acre for trees 4 inches and greater in DBH. Various size classes of trees up to 12 inches were removed from the different blocks, thus reducing the basal area to a range of 43 to 70 square feet per acre. Depending on treatment, production rates ranged fom 2.68 to 10.11 tons per hour. The cost to produce chips ranged from a low of $18.06 per green ton to $45.86 per green ton with variation due to stand characteristics, removal rate, and chip use. Following the thinning, damage to the residual trees was classified as acceptable but the amount of damage increased as the basal area removed, increased. Soil erosion was slight to moderate in the main skid trails and non-detectable on the remainder of the area.

INTRODUCTION

Thinning, as a silvicultural tool, is an important aspect of timber management in the hardwood regions of the United States. Crown release or crown thinning usually results in volume growth of the residual stand which is greater than the unthinned stand (Beck and Della - Bianca, 1975; Graney and Pope, 1978) and can be justified both silviculturally and economically. In well managed stands thinned periodically, this increase in volume growth can approach 35 percent (Harrington and Karnig, 1975) but is dependent on a number of factors including pre- and post-thinning stand densities, average size class, age of the residual stand, and site quality (Roach and Gingrich, 1968). Intermediate thinnings aimed at upgrading the existing stand by removing poor quality growing stock, weed trees and understory rarely enhance residual stand growth (Daie, 1975; Ferguson, unpublished; Weitzman and Trimble, 1957) and have been all but abandoned in many forest

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management programs. Where non-commercial thinnings are practiced, forest managers have used chemical herbicide treatments, girdling or fell-and-leave methods to remove small trees from a stand on a pure-cost, no-return basis.

Rising energy costs and potential disruptions in liquid fuel supplies have caused industries, national planners, and research institutions to look at biomass as an energy source. In particular, forest biomass from thinnings and residues have been identified as a source that could supply, each year, up to 10 Quads (10 x 10^{12} Btus) by the year 2000 to the energy requirements of the United States. Conversion to energy could take the form of gasification, alcohol (methanol or ethanol) production, or direct combustion (industrial and/or private home consumption). The largest supply of forest material exists in timber stands that require thinning for sawlog management. Two forces, then, are coming together to hopefully produce beneficial results here-to-fore not possible: energy needs and timber management needs resulting in biomass for energy from thinnings and well managed timber stands for improved solid wood production.

One critical problem that must be answered, however, is how to remove the forest biomass material economically without excessive damage to the residual forest stand. Successes have been noted in highly capitalized systems, but for many small sized upland (central states) hardwood stands, a small, mobile system may be more practical (Cowdrick et al., 1981). This study was conducted to determine the feasibility of using a small, low-capital-investment, mobile thinning system for the upland hardwoods.

Specific objectives of this research were to determine operational costs by time/production for the shears, grapple skidder and in-woods chipper system, to determine the influence of chip quality, i.e., whole tree vs. bole wood chips, on biomass yield and operational costs, and to determine site and residual stand damage resulting from this thinning system.

METHODS AND EQUIPMENT

Site

The prethinning basal area was 105, 100 and 61 square feet per acre, respectively, for trees 4 inches and greater for blocks 1, 2 and 3. The stand was thinned from below using a diameter limit cut. All stems 4 through 12 inches DBH were removed from block 1, 4 through 10 inches DBH from block 2 and 4 through 8 inches from block 3. Residual stand basal area (ft^2) were 61, 70 and 43 for block 1, 2, and 3, respectively.

Soils

The predominate soil type on the study site was a Zainesville silt loam (Type Fragiudalfs, fine-silty, mixed, mesic) of 6 to 12 percent slope with major inclusions of Wellston silt loam (Ultic Bapludalfs, fine-silty, mixed, mesic) also of 6 to 12 percent slope. Both soils occur on upland sites and are deep, well drained, gently sloping to strongly sloping and have a moderately fine textured subsoil, the lower part of which is a fragipan for the Zainesville soil.

Harvesting Equipment

The equipment selected for use in this study was based on the results of a previous study which evaluated different capacity and capitalized value thinning systems for uses in upland hardwoods (Cowdrick et al., 1981). The equipment selected was: 1) a Dunham, Model 660 Log Skidder 75.5 HP - equipped with a 40 inch opening grapple; 2) a Melroe Bobcat Feller-Buncher, Model 1080, equipped with a 18 inch opening shear; and, 3) a Morbark Model 12 Whole Tree Chipper with a 12 inch chipper throat opening (Fig. 3). Chips were transported by highway chip vans.

A landing area, 150 x 180 feet, was selected at a convenient location for chip van turn-around and skid trail termination and was sized for 2 chip vans, the chipper, a deck for whole tree storage and a skidder turn around area (Figs. 1 and 2).

Reference markers were located along the main skid trails prior to the harvesting operation and ware assessed before, imnediately following the termination of harvesting operations, and one year after harvesting to evaluate soil movement resulting from the harvesting operation and subsequent erosion. Immediately following the harvesting operation, the main skid trails were sown with red fesuce.

The trees were felled and bunched by the feller-buncher with the basal end of the stems (butts) facing the landing, or at an angle to the skid trail (Fig. 4). The skidder transported loads of bunched trees to the landing. Felling, bunching, and skidding were timed as was the chipping phase.

Timing of each operation was based on 100% of each phases' operation. Timing data was recorded in the woods for the feller-buncher and delays of the skidder (i.e., the woods observer timed the feller-buncher operation and noted delays for the skidder), while the chipper and skidder were timed at the landing. Total tonnage came from pulpmill weight tickets. Each machine handled the same weight, hence total tons divided by machine time gives the production rate (or tons/unit time). To create a balanced system, skidder tonnage was doubled (using 2 skidders). Some error might be introduced here since 2 skidders could interfere with each other. For this study, this was assumed negligible.

On arrival at the landings, the trees were deposited either at the chipper, or -- if the chipper had a supply of trees -- on the landing but out of reach of the chipper. The skidder operator would move trees from the storage area to the chipper when necessary.

Main trails were marked but no other skid trails were prepared. The feller-buncher did some clearing of trees from the main trails. The landing was cleared of trees and a small segment was leveled by blading for use by the chip van. The truck road was cut through the timber by felling trees and a moderate amount of blading. Steep sections and soft spots were rocked. These preparation times and costs are not included in the cost figures at the end of this paper.

Residual Stand Damage

All damage to the residual stand was recorded and ploted on a stand map at the time of occurrance, except for root damage estimates which were assessed after activity in a plot was completed. Residual stand damage was divided into three categories: (1) basal stem damage, (2) root damage, and (3) limb breakage, and evaluated for the skidder and the feller-buncher (F/B). Basal stem damage was defined as any alteration in the bark and cambial tissue which resulted in the exposure of the inner wood. Examples include fisures and bark separation, and removal of bark and cambium resulting from impacts with the machinery or in tree felling and skidding operations. Root damage was defined as the exposure or severing of roots.

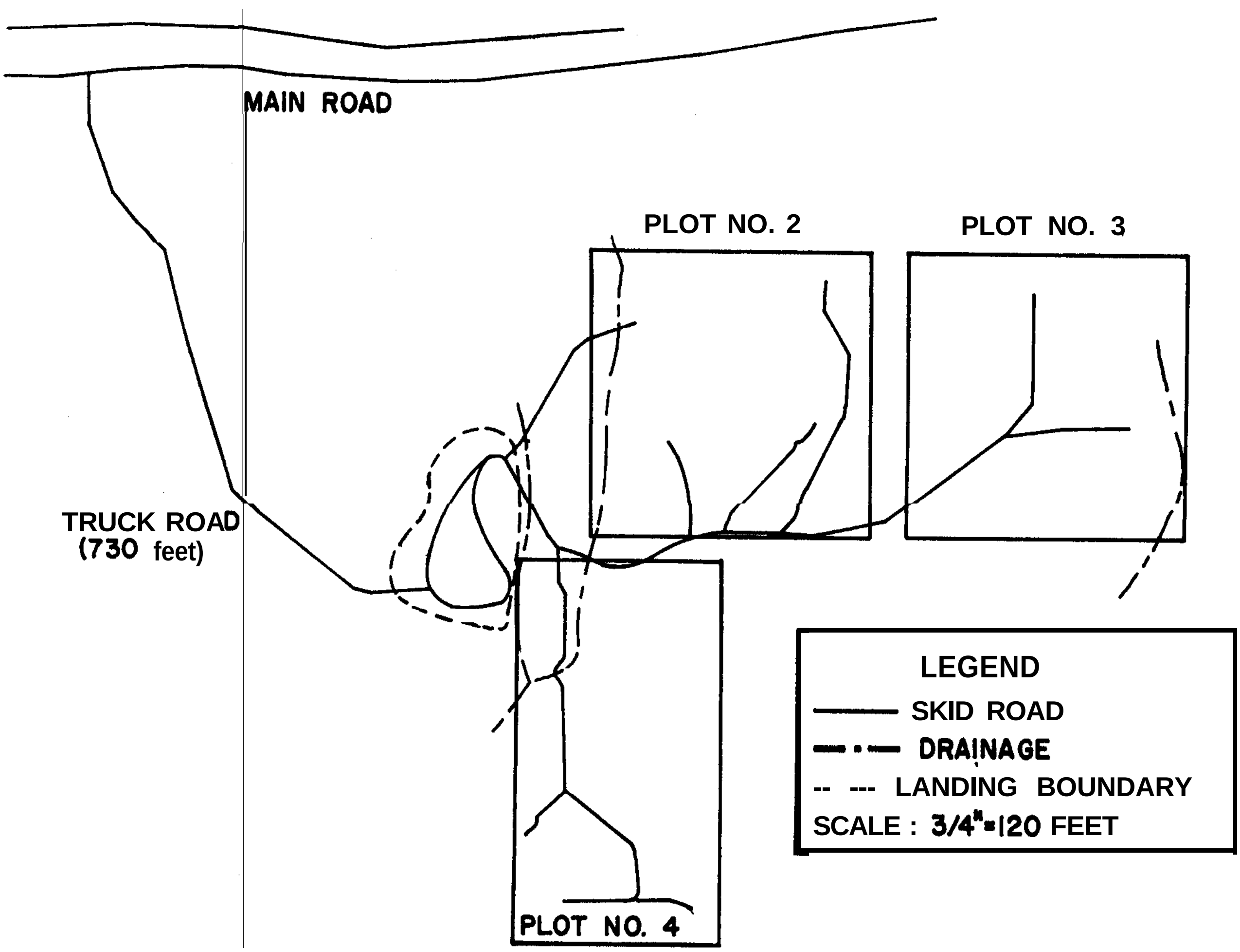

Figure I. Harvest Plot Locations with Truck Rood, Landing, and Main Skid Road.

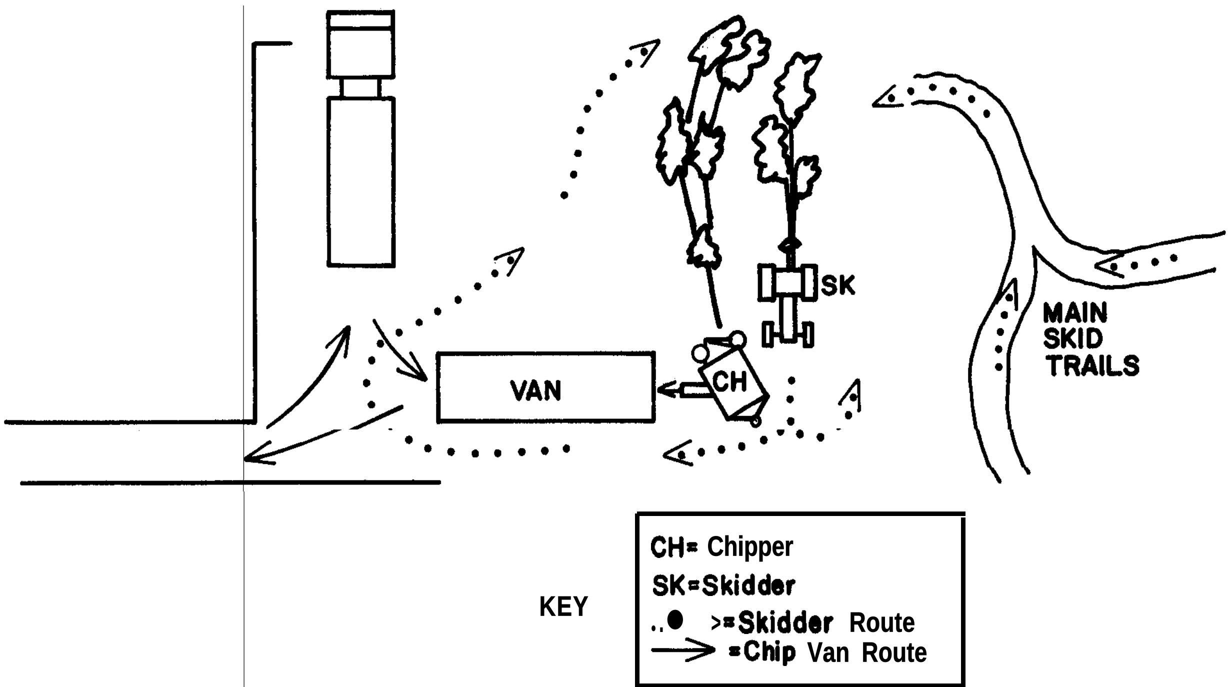

Figure 2. Landing layout and traffic flow.

Figure 3.--Harvesting equipment used in study. Feller-buncher at left and skidder, chipper, and chip van at right.

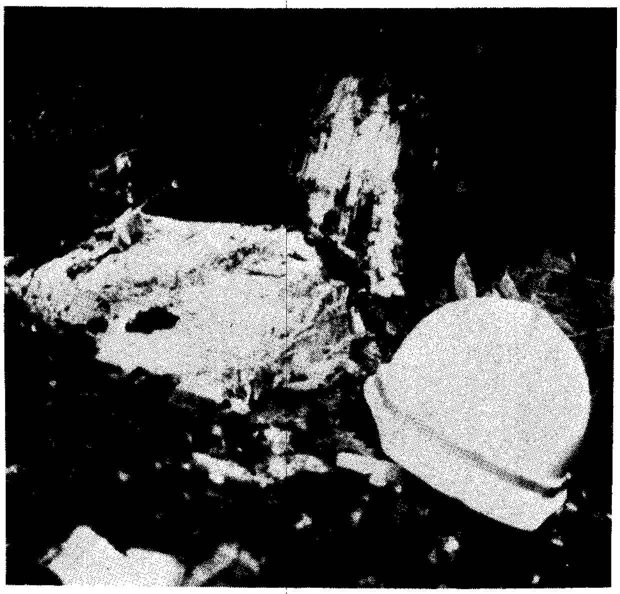

Figure 4 .--One of the cull trees sheared and chipped in study.

Limb breakage was recorded for all limbs two inches and larger on trees of the residual stand.

The damage to each residual crop tree, by the skidding and felling operation, was examined after completion of the thinning. The wound surface area of trees barked by the skidder or feller-buncher was estimated by two measurements at right angles to each other. Total damage in square inches by the skidder and feller-buncher and as a percent of the total crop trees damaged was determined. Limbs broken in the felling operation were recorded by two diameter classes: limbs greater than 4" diameter at the bole, and limbs less than 4" at the bole. Limb diameter up in the crowns had to be estimated. Damage to root systems was recorded if skid trail ruts exposed crop tree roots. Boot damage was expressed as the percent of total crop trees damaged.

RESULTS

Harvesting costs were determined using standard methods developed by Miyata (1980). The processing rate for each operation was calculated from the number of trees handled and the time used in each separate phase (felling, bunching, skidding, and chipping) . The processing rates are given in Table 1.

Belays

Delays occurred primarily in the chipping phase of the system. Because of the limited intake on the chipper, 24 to 36 inches from the butt end of 44 trees had to be removed by chain sawing before chipping could be completed. Total delay, including skidder caused delays, amounted to 36.0 minutes of 47 percent of the total chipping time.

Costs

Production costs were established using a balanced harvesting system. The lowest producing unit was the skidder at 0.059 tons per minute. Using simulation, the system was balanced by adding a second skidder that results in a production- table as follows for block 1 (considered typical for this type of operation):

Feller/Buncher	0.171 tons/min	(pulp chips)
Skidder	0.118 tons/min	(pulp chips)
Chipper	0.185 tons/min	(pulp chips)

A higher production chipper would necessitate the addition of a third skidder to offset the over production of the feller-buncher but for this system, two skidders are sufficient. Equipment and labor costs used to determine system costs are given in Table 2. Table 3 gives the cost for pulp chips where the top chips (<4 inch main stem) were chipped but deposited in a pile beside the van.. Table 3 also reflects the

Table 1. Processing Bate (Time) for Each Function

	Block #1		Block #2		Block #3	
	Trees per min.	Tons per min.	Trees per min.	Tons per min.	Trees per min.	Tons per min.
Fell-Bunch	0.73	.273 (.171)	0.89	.265 (.165)	1.25	.121 (.061)
Skid	0.25	.094 (.059)	0.32	.095 (.059)	0.76	.073 (.045)
Chip	0.79	.296 (.185)	0.85	.253 (.158)	1.30	.126 (.079)

NOTE: Values in () are for pulp chips where top weights are not included in processing rates.

Table 2. Equipment and labor costs.

Machine	Labor	Machine Hate $/Prod. Hr.[1]	Labor Hate $/Prod. Hr.	Total Cost/Hour $/Prod. Hr.
1 Bobcat Feller Buncher	1 Oper.	23.14	9.23	32.37
2 Dunham 660 Log Skidder	2 Oper.	30.46	14.92	45.38
1 Mobark 12" Chiparvester	1 Oper.	31.96	8.00	39.96
1 Fuel & Maintenance Truck	--	5.68	--	5.68
2 Chainsaws	--	3.80	--	3.80
1 Landing Worker	1	--	5.00	5.00
			Total	$132.19/hr

[1] Total cost per productive hour includes utilization rates per Miyata and Steinholb, 1981. Does not include trucking.

Table 3. Removals for Pulpwood Use [stem wood to a 10 cm (4 inch) top] and Harvesting Cost for Each Plot.

Block	Removals ton/acre[1]	Prod. Hate ton/hr	Cost/ton[2]
1 (4" to 12")	27.14	7.08	$25.91
2 (4" to 10")	18.30	7.08	29.22
3 (4" to 8")	7.71	3.66	45.86

[1] Available for pulpchips (without tops).

[2] 55 mile transportation distance.

Table 4. Removals for Energy Use (total tree weight including branches) and Harvesting Cost for Each Plot.

Block	Removals ton/acre[1]	Prod. Rate ton/hr	Cost/ton[2]
1 (4" to 12")	43.63	11.28	$18.06
2 (4" to 10")	29.42	11.40	20.13
3 (4" to 8")	12.39	7.26	30.47

[1] Includes tops.

[2] 55 mile transportation distance.

cost of hauling 55 miles, one-way to a pulpmill[1]. Costs per ton of fuel and pulp chips are given in Tables 3 and 4. Table 4 shows the costs of producing chips for an (hypothetical) energy plant located 55 miles from the harvesting site. The weight of chips from tops (branches and leaves) was incorporated into the production figures for this table. The separate machine costs per hour as given in Table 2 were used, along with production rates, to determine the cost per ton figures in Tables 3 and 4.

Residual Stand Damage

Damage to the residual stand is given in Table 5. Most of the damage was caused by the skidding phase of the operation where 11 to 18 percent of the residual trees were damaged (bark removed) near the bottom of the tree (Fig. 5). Maximum damage by the feller-buncher was 1 percent. Hoot damage could not be separated by machine so skidder and feller-buncher damage are combined. Hoot damage ranged from 1 to 7 percent. Limb breakage on residual trees was caused solely by the feller-buncher and ranged from 2 to 5 percent.

DISCUSSION

The equipment studied does provide a mobile system to thin upland hardwoods (Fig. 6) . The costs of producing pulpchips with this system is not competitive with larger equipment when chips from the tree tops cannot be used. However, energy chip costs (which includes tree tops) are close to competitive prices for some non-renewable sources of energy. In some locations, this system could produce energy chips at a cost

[1] Note: Actual distance was 110 miles with proportionally higher transportation costs. The shorter distance was selected as being more realistic.

Table 5. Residual stand damage (as percent of remaining trees).

Block	Basal Stem Damage Skidder	Basal Stem Damage F/B[1]	Basal Stem Damage Total	Root Damage Skidder + F/B	Limb Breakage F/B	Removed	Residual Trees per Acre
1 (4"-12")	18%	1%	19%	7%	3%	85	58
2 (4"-10")	11%	1%	12%	5%	5%	31	75
3 (4"-8")	1%	0%	1%	1%	2%	73	59

[1] F/B = Feller-Buncher.

Table 6. Conventional Fuel Costs and Equivalent Wood Costs.

Coal -- \$32/ton (13000 Btu/lb) 80% Combustion efficiency	Wood -- \$6.25/ton (3500 Btu/lb) 60% Combustion efficiency
Oil -- \$1.30/gal (140,000 Btu/gal) 80% Combustion efficiency	Wood -- \$43.00/ton
Natural Gas -- \$3.30/100 ft^3 85% Combustion efficiency	wood -- \$17.00/ton

Note: Fuel costs used are for 1981.

Figure 5.--Residual tree damaged in skidding.

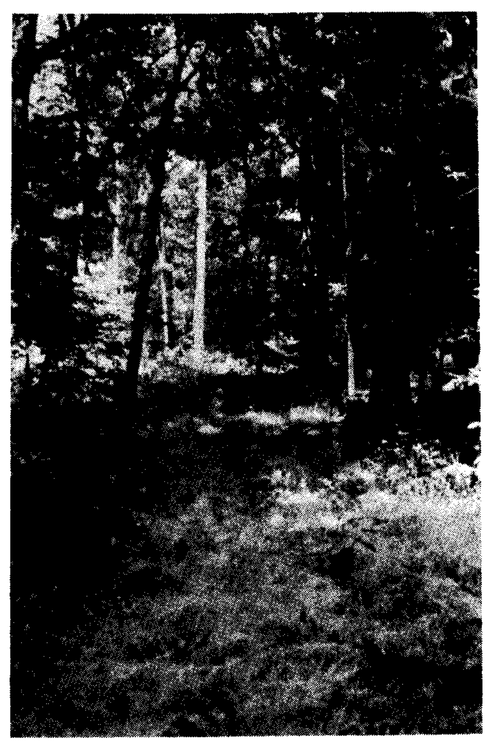

Figure 6.--One of main skidroads after logging.

Table 7. Thinning degree by block.

Block #	No. trees Before	After	No. trees removed	BA (ft^2/A) Before	After	BA removed
3	264	118	146	63	42	21
2	213	151	62	103	70	33
1	285	116	169	105	61	44

comparable with alternative conventional energy sources. Using Arola and Myata's (1981) method of determining breakeven costs for wood vs. other fuels equivalent wood prices to equal conventional fuel are given in Table 6.

The lowast cost of producing wood from our study was $18.06/ton which does not include profit or stumpage. Using a 25% profit margin and a $2/ton stumpage value, the lowest cost jumps to $25.08 per ton. Referring to Table 6, this cost is not competitive with coal at $6.25/ton, is more than natural gas, but is less than oil where the equivalent wood cost is $43.00/ton.

The diameter limit cut (intermediate cut) in effect left the stand structured for a shelterwood system. The objective of the thinning, from the silvicultural perspective, was to maintain adequate density in the size class of the main stand - the bulk of the dominant and co-dominant trees - and provide formable conditions for oak regeneration. The reduction in basal area to 42, 70 and 61 ft^2 (Table 7) should open the stand to encourage natural regeneration and efforts are underway to monitor and stimulate reproduction by desirable species. Based on the Roach and Gingrich (1968) stocking guide block 3 was over-thinned and blocks 1 and 2 are just above the B curve but are classified as fully stocked. Block 3 was located in an old field abandoned 60-75 years ago. The stem diameters and species composition of this block certainly reflect its recent old field history.

It should be restated emphatically, at this point, that the objective of the study was to determine the costs of removing small trees from a stand using three different removal size ranges. The methods used are not necessarily good forestry practices and, in one case (the removal of 4 to 8 inch trees, block 3, an advanced old field succession situation) proved to be completely uneconomical, as well. What we have done is harvest small trees from a mixed upland hardwood stand using a thinning-from-below technique and done it with a small, mobile system at a cost that is presently competitive with higher cost fuels. We do not recommend this technique without modification. Some selectivity needs to be made in marking trees in the 4 to 12 inch DBH range to avoid removing trees of good form and species that have higher commercial value (white oak, etc.). Also, we believe that some trees larger than 12 inches should be removed. Those trees of poor form and of low commercial value for solid wood products. Removing these larger trees becomes a handling problem, however, for this small equipment. These trees would probably have to be felled by chainsaw and possibly bucked into pieces for the skidder to handle.

A larger capacity chipper is needed, not only for a modified technique where larger trees are taken, but also for the size of trees removed in this study.

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APPENDIX

Table Al. Trees by Species and Size in Block 3.
(Removal of 4" to 8" Diameter, 264 trees total, 2.06 acres)

Tree type	% in Block 4"	6"	8"	Total
Oak	2.65	4.55	3.03	10.23
Maple	8.33	9.47	3.03	20.83
Ash	0.76	1.90	2.27	4.93
Hickory	1.52	3.03	2.27	6.82
sass	22.73	9.09	0.76	32.58
Other[1/]	10.98	10.98	2.65	24.61
Total	46.97	39.02	14.01	100.00

Table A2. Trees by Species and Size in Block 2.
(Removal of 4" to 10" Diameter, 213 trees total, 2.06 acres)

Tree Type	% in Block 4"	6"	8"	10"	Total
Oak	2.35	12.20	16.90	20.66	52.11
Maple	2.35	8.92	3.29	- 0 -	14.56
Ash	1.88	5.63	3.29	2.35	13.15
Hickory	2.82	6.10	5.63	3.76	18.31
Other[1/]	0.47	0.47	0.47	0.47	1.88
Total	9.87	33.32	29.58	27.24	100.01

Table A3. Trees by Species and Size in Block 1.
(Removal of 4" to 12" Diameter, 285 trees total, 2.06 acres)

Tree Type	% in Plot					
	4"	6"	8"	10"	12"	Total
Oak	2.46	7.02	8.77	10.18	9.12	37.55
Maple	4.21	5.26	2.81	1.40	- 0 -	13.68
Ash	0.35	1.05	0.70	1.05	1.05	4.20
Hickory	5.26	8.77	9.82	9.82	9.12	42.79
Other[1/]	- 0 -	1.05	- 0 -	0.70	- 0 -	1.75
Total	12.28	23.15	22.10	23.15	19.29	99.97

[1/] "Other" includes Sassafras, Ironwood, Blue Beech, Beech, Dogwood, and Hawthorn (except in Table 1 where Sassafras is included).

OPERATIONAL CHARACTERISTICS OF A HARVESTER IN INTERMEOIATE CUTTINGS[1/]

Bryce J. Stokes and Donald L. Sirois[2/]

Abstract.--The felling and processing capabilities of the Makeri 33T, a small Finnish harvester, were evaluated in a thinning operation in a southeast Louisiana loblolly plantation. Cutting patterns tested were select thinning with and without access corridors. The effect of product length on production was also evaluated, Regression analyses were used to establish production rates for the alternatives. Highest production was for tree-length product length at close corridor spacings, Residual stand damage and soil compaction were measured for each operating procedure. There was a slight soil bulk density increase in areas where the machine operated. An average of 32 percent of all residual trees per acre had some type of bole damage.

INTRODUCTION

Technological prerequisites for thinning equipment include low capital cost, high production, and minimal disturbance to the soil and residual trees. Such economical and environmentally sound systems can increase production from small ownerships and can be used on large industrial and Federal forest lands as well. Efficient, low-cost, thinning systems for small tracts are needed and are being developed.

The Makeri (fig. 1) is a small multifunctional machine, capable of felling, limbing, and bucking single stems. Prototype units have been operating in the South since early 1981. The Makeri was evaluated in a 14-year-old seeded loblolly plantation in southeastern Louisiana. Production studies were performed for different operating procedures. Soil compaction and residual stem damage data were also collected.

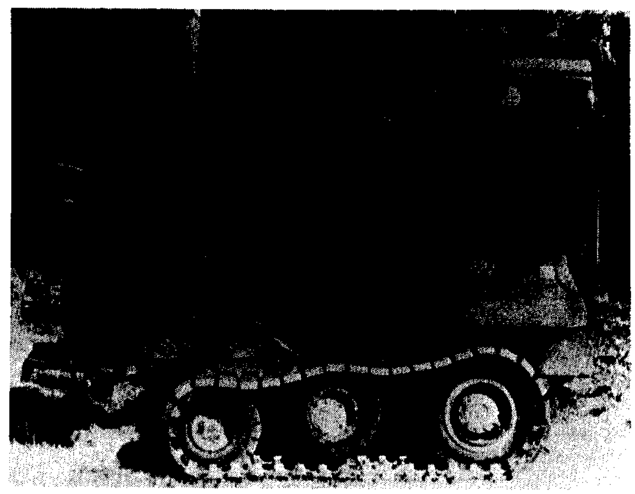

Figure 1--Makeri Harvester

PROCEDURES

Two thinning procedures, pure-select and corridor-select were studied over a range of removal levels, corridor spacings, and product lengths (See test block description). If the block was to be a corridor test, then a 10 ft wide corridor was flagged at the appropriate spacing. The access corridor meandered around the best quality trees leaving them in the stand where possible. The width of the corridor was at least 10 ft but would vary depending on spacing of removal trees. Every tree within the flagged corridor was cut.

[1/] Paper presented at the Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Test Blocks

Block No.	Removal Percentage	Thinning Method	Corridor Spacing (ft)	Product Length (ft)
1	40	Select	--	5
2	48	"	--	5
3	61		--	5
4	45		--	10
5	52	Corridor	30	5
6	64	"	30	5
7	68	"	30	5
8	62	"	30	10
9	48	"	30	24
10	46	"	30	Tree Length
11	45	"	50	5
12	51	"	50	5
13	60	"	50	5
14	64	"	50	10
15	56	"	50	24
16	71	"	50	24
17	53	"	50	Tree Length
18	56		100	5
19	45		100	5
20	55	"	100	24
21	57	"	100	Tree Length

Cycle Elements

Element	Explanation
Move to tree	Time element began when the shear head was returned to upright position after dropping the tree top from the previous cycle. Element ended when frontal plane of shear crossed frontal plane reference point of tree to be sheared.
Position and shear	Element began when tree first entered shear. This element ended with initial movement of the tracks after severing the tree from the stump.
Move to process area	Initial movement of tracks after shearing was the beginning of this element. The end was signified by cessation of tracks at the point of processing.
Limb and buck	Time element began with cessation of the machine track movement at process area. This element included lowering of stem, movement for pile location, limbing and bucking. The element also included releasing the tree top and concluded after the empty shear head was returned to upright position.

After the corridors were flagged, all leave trees in the block were marked. Selection of residual trees was based on a combination of size, quality and spacing factors. A tree tally was made to determine the initial stocking and residual trees for each block. In the pure select test blocks (no corridors), the trees to be cut were tagged with numbers and the X, Y coordinates were measured and recorded along with diameter at breast height (dbh). For the blocks with corridors, the trees in the strip between two corridors and in the corridors were numbered. Distance from the center of the left corridor was measured and recorded for each tree. Elements of the harvesting cycle were timed while harvesting the blocks. Approximately 20-30 cycles were timed per block (See cycle element description).

RESULTS

Levels of tree removals per block were controlled to determine the effect on production and stand impact. Before thinning the plantation had an average of 649 trees per acre (Table 1). For all the tests, an average of 356 trees per acre were removed with a range of 173-672 trees per acre. The harvested trees had an average dbh of 5.3 in, an average total height of 48.7 ft, and an average crown of 14.0 ft. The average merchantable volume per stem was 3.1 cu. ft. Tops were cut at a merchantable limit of "3 inches", outside bark diameter.

Data used in the analysis was the productive time measured during harvesting of test blocks. A summary of the cycle data is shown in Table 2. Regresssion techniques were used to develop prediction equations for each cycle element.

Table 1--Stand and Stem Characteristics.

Type of Blocks (No. of Blocks)		Trees per Acre Total	Trees per Acre Removed	Trees per Acre Residual	dbh in	Harvested Trees Merch. Height ft	Harvested Trees Crown ft	Harvested Trees Merch. Vol. cu. ft.
All (21)	Mean	649	356	294	5.3	32.9	14.0	3.1
	Std dev	184	117	100	1.2	5.6	1.6	1.9
	Min	384	173	190	2.8	21.8	10.8	0.0
	Max	1120	672	548	9.8	52.4	19.7	9.2
Select (4)	Mean	630	329	302	4.8	30.6	13.3	2.4
	Std dev	124		75		5.5	1.4	1.8
	Min	464	112	225	3.0	21.8	11.1	0.0
	Max	800	523	403	9.0	48.8	18.7	9.2
Corridor (17)	Mean	655	364	291	5.4	33.3	14.1	3.2
	Std dev	202				5.5	1.6	1.8
	Min	384	123	198	122.8	22.2	10.8	0.0

Table 2--Time Study

Time Per Tree (Minutes)

Type Block No. (obs)		Travel to Tree	Shear	Travel to Pile	Delimb & Buck	Total Travel	Total Cycle
All							
21	Mean	.17	.08	.14	.47	.32	.85
(409)	Std dev	.12	.08	.10	.19	.17	.26
	Range	.01-.82	.01-.91	.00-.58	.13-1.71	.06-.90	.32-2.05
Select							
4	Mean	.21	.08	.11	.46	.32	.84
(63)	Std dev	.18	.07	.08	.20	.20	.28
	Range	.03-.82	.01-.44	.00-.58	.17-1.08	.08-.89	.32-1.67
Corridor							
17	Mean	.16	.08	.15	.47	.31	.86
(346)	Std dev	.10	.08	.10	.20	.16	.26
	Range	.01-.65	.01-91	.01-.53	.08-1.71	.06-.90	.37-2.05
Length 5'							
11	Mean	.14	.08	.11	.56	.25	.89
(133)	Std dev	.12	.06	.10	.25	.15	.31
	Range	.01-.82	.01-.45	.00-.58	.08-1.71	.06-.89	.32-2.05
Length 10'							
3	Mean	.17	.05	.10	.43	.28	.76
(80)	Std dev	.14	.03	.05	.15	.15	.20
	Range	.01-.73	.01-.24	.03-.34	.17-.86	.09-.82	.37-1.41
Length 24'							
4	Mean	.19	.08	.18	.42	.39	.89
(125)	Std dev	.11	.10	.10	.17	.16	.26
	Range	.02-.65	.01-.19	.01-.50	.13-1.02	.08-.90	.45-1.82
Tree-Length							
3	Mean	.17	.08	.19	.43	.35	.86
(71)	Std dev	.10	.09	.11	.13	.190	.24
	Range	.01-.50	.01-.75	.01-.51	.17-.80	.10-.76	.40-1.35
30' Spacing							
6	Mean	.14	.07	.13	.46	.27	.80
(96)	Std dev	.08	.04	.08	.23	.11	.27
	Range	.04-.37	.01-.27	.01-.41	.08-1.71	.11-.59	.43-2.05
50' Spacing							
7	Mean	.16	.08	.13	.48	.29	.84
(149)	Std dev	.11	.10	.08	.19	.15	.26
	Range	.01-.65	.01-.91	.01-.42	.13-1.12	.06-.80	.37-1.82
100'Spacing							
4	Mean	.19	.08	.22	.47	.41	.95
(101)	Std dev	.11	.07	.13	.20	.20	.26
	Range	.04-.56	.01-.75	.01-.53	.16-1.25	.08-.90	.45-1.64

Analyses for prediction equations were completed on a per tree basis. The position and shear element of the production cycle was analyzed first because of the limited mechanics involved. The only significant variable found for this element was dbh (Table 3). No trees larger than shear capacity were encountered. Other variables tested did not significantly influence this element. Because this study was completed in one stand that had little variation in brush and slope conditions, these variables were not tested in the analysis.

The second element modeled was delimbing and bucking. Variables that described the tree characteristics and operating procedure were evaluated. The most significant variables were those of merchantable height of the tree and the interaction of height with number of bucks or cuts. The division of merchantable height by product length was used to estimate the number of bucks.

The travel to the tree and travel to the process area were combined for total travel time per tree. There was a significant difference between select and corridor thinning so travel times per tree were analyzed separately. In the prediction equation for total travel time per tree for thinning stands with corridors, the logical factors were spacing between corridors, spacing between trees to be cut, tree size, and product length. Trees removed per acre proved to be the most significant variable for estimating travel time. Other variables in the model were the interaction terms of product length and spacing between corridors (Table 3). The variable product length reflects that longwood and tree-length material was carried out of the stand to the corridor. The shortwood was piled along the edge of the access corridor.

Total cycle time per tree can be estimated by combining the elemental regression equations for the corridor thinning. For select thinning the mean travel time is used. In select thinning (fig. 2) the trees must be processed into shortwood to prevent damage to the residual trees during removal of the wood from the stand. Figure 3 presents the production curves for thinning with access corridors spaced at 30 ft intervals. A representative range of dbh, merchantable height, and removed trees per acre were used to develop the curves. Only two product lengths, 5 ft shortwood and tree-length, were used for these graphs. Figure 4 presents the production curves for 100 ft spacing intervals for the same variables.

Using the prediction equations for elements of the cycle and production tables, alternatives can be compared for production. Table 4 shows the estimated production of wood for trees that average 5 inches in dbh and 30 ft in merchantable height.

On a trees-per-productive-machine-hour (pmh) basis, the highest productivity (84 trees per pmh) was estimated to be for the longwood products (24 ft and tree-length) at the closer corridor spacing. The lowest productivity (70 trees per pmh) was tree-length production on 100 ft corridor spacings. The least productive alternative was the select thinning and 5 ft wood.

The product length determines the merchantable volume per stem, which affects production on a volume basis. For 5 inch dbh trees, the highest production alternative is tree-length at 30 ft spacing. The production was 229.7 cu. ft. per productive machine hour. The 24-ft option had the lowest production (169.1 cu. ft. per pmh) because of the wood waste when only one stick could be cut from a tree. These results are comparable with those published by Arvidsson and Spahr (1980). However, these production estimates for each alternative are only for the Makeri harvester and subsequent operations could possibly be affected by the application of this machine. As an example, the piling of the longwood and tree-length material into the corridor could reduce the yarding or forwarding times.

From the data collected before and after thinning, a comparison was made (Table 5) between average stand diameter changes. The heavier removal levels of 60% or more of the trees produced the highest changes in average dbh. Using narrow access corridors of 10 ft, avoiding the best quality trees, can result in a stand that is comparable with the select thinning method.

Table 3. Prediction equations for cycle elements.

Position and Shear Time = 0.40128 - 0.13273 x DBH + 0.01281 x (DBH x DBH) R Sqr. = 0.13
Delimb and Buck Time = - 0.18659 + 0.017689 x Height + 0.00088 x (Height x (Height/Length)) R Sqr. = 0.52
Travel Time (corridors only) = 0.41893 - 0.00052 x Removed Trees + 0.00546 x (Length X Spacing)/100 R Sqr. = 0.24

Where: Time = Minutes per tree.
DBH = Diameter at breast height in inches.
Height = Merchantable height in feet.
Removed Trees = Merchantable trees per acre.
Length = Product length in feet. (Equals merchantable height if tree-length)
Spacing = Distance between access corridors centers in feet.

Table 4--Comparison of production for alternatives.

DBH = 5 in, Merchantable Height = 30 ft. Merchantable Trees/Acre removed = 300.

Type of Thin	Corridor Spacing	Product Length	Trees per PMH	Cu. Ft. per PMH*
Select	---	5 ft	72	191.5
Select	---	10 ft	79	203.0
Corridor-Select	30 ft	5 ft	74	196.8
" "	30 ft	10 ft	81	208.2
" "	30 ft	24 ft	84	191.2
" "	30 ft	Tree-Length	84	229.7
" "	100 ft	5 ft	72	191.5
" "	100 ft	10 ft	77	197.9
" "	100 ft	24 ft	74	169.1
" "	100 ft	Tree-Length	70	191.4

*Merchantable top bole diameter of 3 inches.

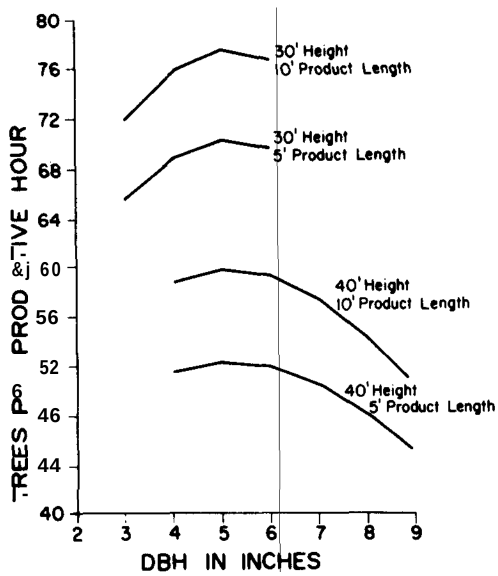

Figure 2--Select Thinning Production

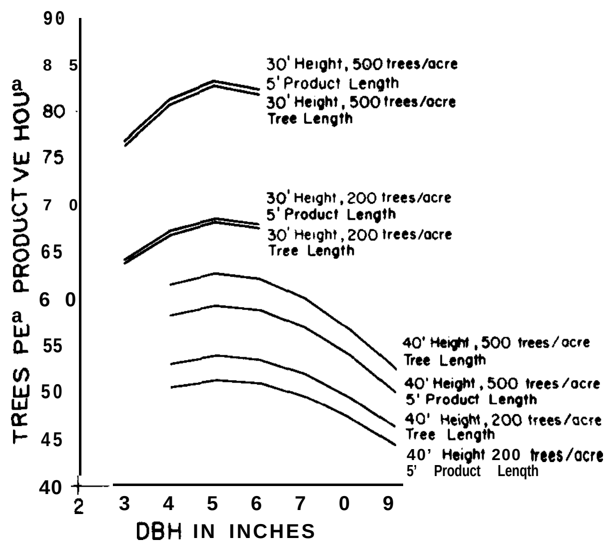

Figure 4--Corridor-Select Thinning Production-
100 Ft. Corridor Spacing

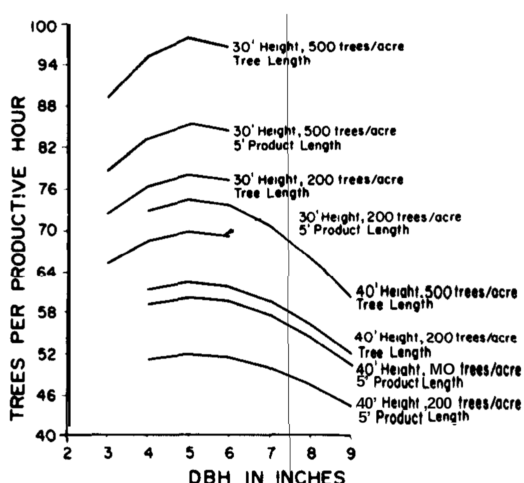

Figure 3--Corridor-Select Thinning Production-
30 Ft. Corridor Spacing

STAND AND SITE IMPACT

Another major objective of the study was to determine the presence and magnitude of stand site impacts on the residual stand. Soil core samples were taken at 2-and 4-inch depths in undisturbed and disturbed areas in the corridor and stand. All bole damage caused by the felling machine was recorded by size and severity.

The moisture content of the soil averaged 20.4 % (dry weight basis). A test of means of the soil bulk density of the disturbed areas and the undisturbed is shown in Table 6. For both depths, there was a significant increase in bulk density in the disturbed sites. At 2 inches deep, the increase was 15 % and 11 % at 4 inches. Soil compaction was less in the stand than in the corridor and seemed to increase with product length and decrease with corridor spacing.

Table 5.--Diameter changes in blocks by method, spacing and removal level.

Blocks	No.	Average DBH per Block (inches) Before	Removed	Residual	Change
All	21	6.0	5.1	7.1	1.1
Select (All)	5	5.7	4.8	6.7	1.0
Method					
<50% Level	3	5.6	4.7	6.3	0.8
>60% Level	2	6.0	5.1	7.2	1.2
Corridor (All)	16	6.1	5.2	7.2	1.1
Method					
<50% Level	4	5.8		6.5	0.7
>50% < 60%	7	6.3	5.0		1.2
>60%	5	6.0	5.2	7.5 7.5	1.5
30' Spacing	6	5.8	5.1		1.1
50' Spacing	7	6.1	5.2	7.4	1.3
100' Spacing	3	6.4	5.4	7.4	l:o

All damage, regardless of size, was recorded (Table 7). For all test blocks, the number of damaged trees per acre was 84.4 or 32%. Of these trees, 47% were along the corridor and 76% had only the bark damaged. The average damage area was 40 sq. in. per tree. Incidence of damage appeared to increase with the number of residual trees per acre. Product length was thought to effect the number of residual tree damaged, but the analysis showed no significant difference among the product length groups. A higher occurance of damage occured on the 30 ft. corridor spacing blocks.

CONCLUSIONS

Production, 84 trees per productive machine hour, was highest for the tree-length product length and closer corridor spacing. Product length affected the travel element and merchantable volume per tree.

Removal levels of 60% or more of trees per acre produced the largest change in average dbh. The residual stand of a tract harvested with narrow corridors at wide spacings (greater than 50 feet) is comparable to one that is select thinned without corridors.

REFERENCES

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   1980. The makeri thinning system-an evaluation of the makeri forwarder in thinning. Forestry Institute of Sweden, 34 pp.

Table 6.--Soil Compaction--Density

		Bulk Density (gms/cc)						
			Undisturbed	No. of		Disturbed		
Test	Class	Mean	St. Dev.	Obs.	Mean	St. Dev.	No.	
Depth	2"	1.15	.18	13	1.32	.12	13	*
	4"	1.29	.10	15	1.43	.12	15	*
Location	Corridor	1.22	.12	10	1.44	.14	10	*
	Stand	1.22	.18	18	1.35	.12	18	*
Product	5'Wood	1.23	.14	20	1.36	.14	20	*
	24'Wood	1.30	.24	4	1.44	.10	4	
	Tree-Length	1.11	.14	4	1.43	.13	4	*
Spacing	30'	1.25	.05	6	1.44	.11	6	*
	50'	1.25	.21	12	1.35	.17	12	
	100'	1.12	.11	6	1.28	.12	6	*
Removal Tree/acre	250	1.21	.18	9	1.30	.17	9	
	300	1.29	.18	6	1.41	.10	6	
	400	1.12	.11	6	1.38	.12	6	*
	450	1.28	.10	7	1.45	.08	7	*
Depth & Location	2"Corridor	1.11	.09	4	1.34	.13	4	*
	2"Stand	1.16	.21	9	1.32	.13	9	
	4"Corridor	1.30	.07	6	1.51	.10	6	*
	4"Stand	1.28	.12	9	1.38	.11	9	

*Significant bulk density increase at 9.5 % level.

Table 7.--Residual Stand Damage

Test	Class	Mean	St. Dev.	No.	
Residual Trees/Acre	100	55.62	31.46	8	
	200	81.43	50.87	7	*
	300	81.43	50.87	8	
Product Length	5'Wood	75.25	65.18	12	
	10'Wood	63.67	95.11	3	
	24'Wood	104.40	47.54	5	
	Tree-Length	108.33	107.95	3	
Corridor Spacing	Select	70.00	70.58	4	
	30'	120.83	76.97	6	
	50'	80.22	25.05	9	
	100'	53.50	27.69	4	

*Significant difference at 95 % level.

ANALYSIS OF THE TAYLOR SKYLINER IN WESTERN NORTH CAROLINA[1/]

Jerry L. Koger and James R. Sherar[2/]

Abstract.--Production rates, production costs, and operating characteristics of the Taylor Skyliner were determined for an 18 acre clearcut in western North Carolina. An average of 2.6 stems, containing 73.9 cubic feet, were harvested per cycle. Average cycle time, including cycle delays but excluding road and landing changes, was 10.8 minutes. Estimated yarding cost for the yarder and four-man crew was $48.24 per cunit.

INTRODUCTION

Conventional ground skidding systems in western North Carolina consist of articulated, four wheel drive, rubber tired skidders and crawler tractors. A few loggers use small, truck mounted, single-drum cable yarders. These systems require a dense network of haul or skid roads. Cable systems are needed that will: (1) provide a positive lift to the logs being skidded, (2) have haulback capabilities, (3) have sufficient span to reduce the density of roads, and (4) operate profitably. The Taylor Skyliner[3/], a medium-sized cable yarder, was studied during operation on a site in the Pisgah National Forest in western North Carolina. Production rates and costs were calculated for the yarder.

STUDY AREA

The 18-acre harvested tract, located on the Pisgah National Forest, is about 30 miles northwest of Asheville, North Carolina. The steep side slopes, deep hollows, and shallow soils with rock outcrops made harvesting difficult. Interference from small trees left standing increased hooking and road changing time.

The silvicultural prescription for the predominately hardwood stand was to clearcut. Approximately 55 percent of the trees were oak, 33 percent yellow poplar, 3 percent maple, and 2 percent hickory. The remaining 7 percent consisted of 11 other species. There were 807 saw-timber trees having a total volume of about 42,334 cubic feet, including topwood. In addition, there were 1,360 smaller trees with a total volume of 14,824 cubic feet.

OPERATION

The Taylor Skyliner was operated as a running skyline. The boundary of the harvested area is shown on the topographic map section in Figure 1. The two landings and 26 cable road (skyline) locations are shown in Figure 2. The harvested stems were yarded uphill to the lower landing and both uphill and downhill to the upper landing. Equipment specifications for the yarder are given in the Appendix (Table 1).

A four man crew was used with the Taylor Skyliner. The crew consisted of two chokersetters, one landing chaser, and one yarder operator. Although the crew was experienced with conventional ground logging systems, they had worked with the Taylor Skyliner for only one month at the time of the study.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1982.

2/ Koger is a Research Engineer at the Forestry Sciences Laboratory, maintained by the Southern Forest Experiment Station, USDA Forest Service, at Auburn, Alabama. Sherar is a Logging Engineer with the U.S. Forest Service in Asheville, North Carolina.

3/ The use of trade, firm, or corporate names-is for the convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others which may be suitable.

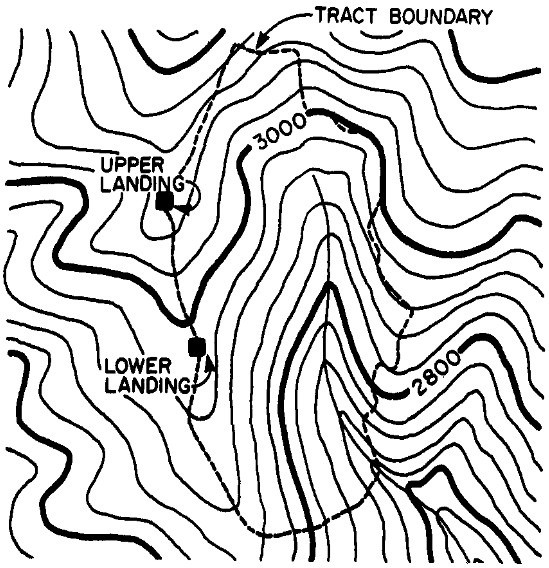

Figure 1.--Harvested area boundary

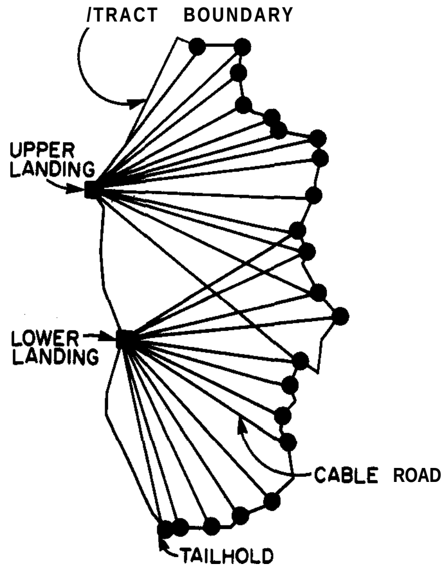

Figure 2.--Landing and cable road locations

MEASUREMENT OF VARIABLES

Time

The snapback method of timing was used to measure the elemental phase of each cycle. The following cycle elements were measured: 1) lift carriage, 2) outhaul, 3) lower carriage, 4) lateral outhaul and hook, 5) lateral inhaul, 6) inhaul, 7) lower stems, 8) unhook, and 9) cycle delays.

Stem Measurement

The length and diameter of all stems yarded were measured. Diameter measurements were made at each end and at several intermediate points, Cubic feet (Smalian's formula) and weight were calculated from these measurements.

Distance

The distance from the landing to the tailhold used on each cable road (skyline) corridor during the study was determined using a hand-held compass, 200-foot tape, and clino- such as rock outcrops, tree snags, and hollows were noted. In addition, colored flagging was tied at 100-foot intervals. The terrain features and colored flagging were used for ocular estimates of the horizontal distance from the carriage to the landing (X, fig. 3). Slope yarding distance (SYD) was calculated by:

$\sqrt{X^2 + (D + D1)^2}$. The relationship of these variables to the cable and ground geometry are shown in Figure 3.

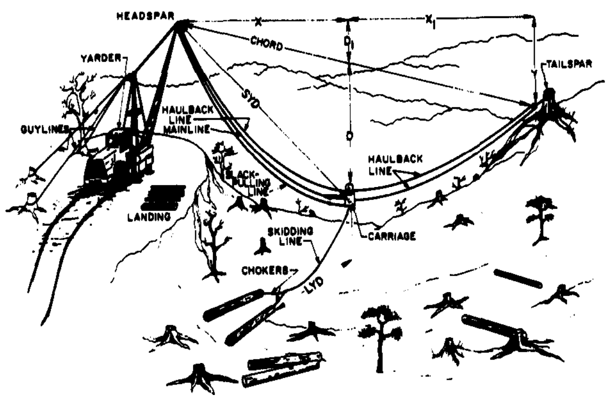

Figure 3.--Running skyline cable configuration

The lateral yarding distance (LYD) was not measured because direct field measurement would have required two additional research personnel and would have interfered with the yarding operation. Indirect measurements were not feasible due to underbrush and steep side slopes. As a result, the influence that lateral yarding distance had on cycle times could not be determined.

DATA ANALYSIS

Production Rates

The average cycle time for a four man crew was 10.80 minutes (Table I). This does not include the time required to change cable roads (53.40 minutes) nor the time to move landings (estimated at 300 minutes by the logger). The average volume yarded per cycle was 73.86 cubic feet (inside bark). The number of stems yarded per cycle ranged from 1 to 5 with an average of 2.6, Assuming a uniform stand distribution, approximately 0.7 acre (2,223 cubic feet) was yarded per cable road and 9 acres (28,579 cubic feet) were yarded per landing. The mean, standard deviation, range, and number of observations are given in Table I. The percent distribution of the cycle elements is shown in Figure 4.

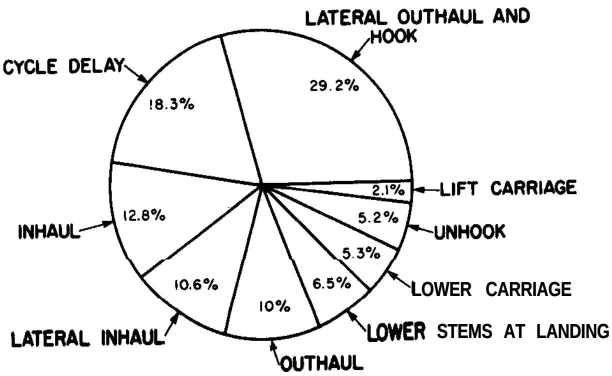

Figure 4.--Percent distribution of cycle elements.

Regression equations developed for uphill yarding are shown in Table II. Slope yarding distance and cubic feet per turn were significant (alpha = 0.05) in predicting cycle time. The number of stems yarded per cycle, stem length, or stem diameters were not significant. The R-squres that were obtained are slightly lower than those reported in other studies such as Dykstra (1975). Possible reasons for the explanation of the variation in cycle elements in this study include: (1) crew inexperience with cable systems (2) a prototype yarder, (3) small standing trees which interfered with outhaul and inhaul, and (4) ocular estimates of yarding distances.

Production Costs

In order to determine production costs, several assumptions were made concerning equipment efficiency, equipment life, and interest rates. As used in this study, equipment efficiency is the product of yarder availability and yarder utilization. Insufficient data were collected in this study to determine equipment efficiency. Wellburn (1976), Hensel and Johnson (1977), and McMorland and Wong (1982) have reported values for equipment efficiency ranging from 0.21 to 0.84. Considering that the yarder observed in this study was a prototype and that the crew was not experienced in cable logging, an equipment efficiency of 0.60 was assumed. Additional assumotions are listed in Table 2 of the Appendix. The method used to compute fixed and variable costs is similar to those described by Mifflin and Lysons (1978) and Miyata (1980).

The estimated cost for the Taylor Skyliner and a four-man crew was $98.80 per scheduled hour. Total estimated yarding cost for the 18 acre tract was $27,573.10, which is about $48.24 per cunit (100 cubic feet). This is an equivalent cost of $14.84 per ton, $111.15 per thousand board feet (Doyle), $83.32 per thousand board feet (1/4" Int.), or $57.22 per cord. The above equivalent costs are based on the assumption that 1 cubic foot (inside bark) is equal to 65 pounds, 4.34 board feet (Doyle), 5.79 board feet (1/4" Int.), or 0.008431 cords. This does not include costs associated with moving-in and setting up at the first landing, the partial use of support equipment, or a margin for profit and risk on the investment. The equation used to calculate tract harvest time is listed in the Appendix.

DISCUSSION

Steep slopes, shallow soils, and rock outcrops made harvesting difficult. Setting chokers was time consuming, and finding firmly anchored tailhold trees (or stumps) was a problem. The labor intensive activities of pulling the skidding line out, hooking, and unhooking accounted for 34.4 percent of the cycle time. Only 20 percent of the variation in cycle times could be explained by yarding distance and volume per cycle, Production might have been increased by coordinating felling with yarding, presetting chokers, and increasing lateral yarding distances.

Table I.--Characteristics of selected variables for uphill yarding

Variable Description	Mean	Standard Deviation	Range	Number of Observations
Cycle Elements (min)				
1. lift carriage at landing	0.23	0.13	0.10 - 0.70	44
2: outhaul (150-650 ft)	1.08	0.36	0.30 - 2.25	62
4. lower carriage in woods	0.57	0.32	0.05 - 1.55	60
5. hook (2 men)	3.15	1.42	1.05 - 6.80	62
lateral inhaul (0-100 ft)	1.15	1.01	0.40 - 7.30	64
6. inhaul (150-650 ft)	1.38	0.81	0.45 - 4.45	65
7. lower logs at landing	0.70	0.92	0.10 - 5.10	63
8. unhook (1 man)	0.56	0.47	0.50 - 2.00	54
9. delay	1.98	1.68	0.00 - 7.10	66
10. Total Cycle	10.80	3.32	5.10 20.40	32
Cycle Volumes and Stem Characteristics				
1. cubic ft (inside bark)	73.86	37.27	9.40 - 198.70	32
2. number stems	2.60	1.12	1 - 5	66
3. stem length (ft)	45.99	12,85	26.10 - 88.50	66
4. large end diam. (in)	12.33	4.65	5.00 - 29.40	170
5. small end diam (in)	6.47	2.81	2.00 - 16.80	170
6. d.b.h.(in)	9.98	3.46	4.40 22.08	170
Cycle Yarding Data				
1. slope yarding distance (ft)	520	110	150 650	66
2. chord slope (%)*	-49	18	-20 - 100	66
Non-Cycle Delays (min)				
1. change cable roads	53.40	9.67	46.20 - 60.60	2
2. change landings (logger's estimate)	300			

*Chord Slope was calculated by: (-(D + DI)/X)*100 for each yarding cycle (see Figure 3).

Table II. Regression equations developed for uphill yarding

Yarding Phase	Regression Equation	R-SQ	cv	SE
Outhaul *	Y=0.45 + 0.0012 (SYD)	0.14	31.32	0.34
Inhaul t	Y=0.06 0.0015 (SYD) + 0.0078 (FT3)	0.12	56.06	0.77
Total Cycle #	Y=2.10 + 0.0061(SYD) + 0.0537 (FT3)	0.20	33.63	2.19

Y = time, in minutes, for the given cycle phase
SYD = slope yarding distance, in feet
FT3 = cubic feet (inside bark) per cycle
* based on 62 observations
t based on 64 observations
\# based on 32 observations for which complete data was obtained on each element of the cycle (see Table I)

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APPENDIX

Table 1. Equipment description of the Taylor Skyline cable yarder*

Item	Description			
Manufacturer	Taylor Machine Works, Inc. P. O. Box 1150 Louisville, Mississippi 39339			
Model Carrier	Taylor Model T-598 articulated, four-wheel drive, front-end loader			
Engine	4-71 Detroit Diesel			
Tires	18:00x24-28PR			
Tower				
Height	54 feet			
Construction	inclined, heavy lattice steel, A-frame			
Erection	hydraulic			
Yarder Capabilities	running, standing, slacking, or gravity skyline			
Drum Characteristics:	Line Speed ft/min	Line Pull lbs	Line Size in	Drum Capacity ft
haulback drum	1,349-1,569	16,000	5/8	2,500
main & front drums	1,220-1,419	31,000	5/8	1,250
straw drum	2,750	10,000	5/16	3,600
guyline drums	135	3,500	3/4	250
Weight	65,000 pounds			
costs	$475,000.00 (actual costs depends on options)			

*Based on information supplied by manufacturer and from Hawkes (1979).

Table 2. Equipment costs for the Taylor Skyline cable yarder (1982 price estimates)

Item Description	Annual cost	Hourly cost
Fixed Costs:		
Depreciation		
Taylor Yarder ($475,000-$97,599.92)/8	$ 47,175.01	$23.59
Carriage ($4,875-$975)/8	487.50	0.24
Taxes, Interest & Insurance		
(20% of Average Annual Investment)	62,389.19	31.19
Variable Costs:		
Maintenance & Repair (50% x $47,175.01)	23,831.25	$11.92
Fuel ($1.30/gal. x 5.81 gal./opr. hr.)	9,059.23	4.53
Oil, Grease, Etc. (20% x $9,059.23)	1,811.94	0.91
Tire Replacement (1 set/7 years)	371.43	0.19
Tire Repair (10% x $371.43)	37.14	0.02
Wire Rope:		
Main ($0.96/ft x 1250 ft x 0.50)	600.00	0.30
Haulback ($0.96/ft x 2500 ft x 0.33)	792.00	0.40
Slack-pulling ($0.96/ft 1250 ft x 0.05	600.00	0.30
Strawline ($0.50 x 3600 ft x 0.50)	900.00	0.45
Guylines ($1.90 x 400 ft x 0.33)	250.80	0.13
Chokers ($12.50/choker x 5 chokers x 20)	1,250.00	0.63
	$ 39,502.99	.78
Labor costs (4 men x $6.00/hr x 2,000 hr/yr)	$ 48,000.00	$24 .00
	,554.	

Assumptions: Years Life = 8, Salvage Rate = 20%,
Scheduled Hours = 2,000/year, Operating Hours = 1,200/year
Labor Rate = $6.00 per scheduled hour and includes overhead, insurance, and social security.

Equation used to compute tract yarding time:

Y=((X1/X2)X3 + (X1/(X4*X5))X6 +((X1/(X5*X7))-1)X8)/X9

where: Y = tract yarding time
X1 = tract volume
X2 = average volume yarded per cycle
X3 = average cycle time
X4 = number acres harvested per cable road
X5 = volume per acre
X6 = average road change time
X7 = number acres harvested per landing
X8 = average landing change time
X9 = operating hours per year/scheduled hours per year
or machine availability * machine utilization

In this study the following values were used: X1 = 57158 cubic feet, X2 = 73.86 cubic feet, X3 = 10.8 minutes, X4 = 0.692, X5 = 3175 cubic feet, X6 = 53.4 minutes, X7 = 9 acres, X8 = 300 minutes, and X9 was assumed to be 0.6. Using these values in the above equation, then:

Y = ((57,158/73.86)10.8 + (57,158/(0.692*3,175))53.4 + ((57,158/(3,175*9))- 1)300)/0.60
Y = (8,357.79 + 1,389.21 + 300)/0.60
Y = 10,047/0.60
Y = 16,745 (or 279.08 scheduled hours)

FINANCIAL ANALYSIS OF EQUIPMENT:
A GENERAL APPROACH TO SELECTION,
REPLACEMENT, AND MACHINE COST PROBLEMS"

W. L. Mills, Jr., and Robert A. Tufts [2/]

ABSTRACT -- An approach to analyzing equipment selection, replacement and machine cost problems is explained and the use of the results demonstrated. After tax annual equivalent costs are calculated using a six-etep procedure. Sample decisiona involving the determination of optimal economic life, equipment replacement and selection, and coot per unit output are discussed.

INTRODUCTION

The increasing mechanization of harvesting and forest management activities coupled with the high coat of most forestry equipment mean8 that foresters, in both procurement and land management, must make complicated and expensive equipment decisions. The analysis presented below will help foresters weigh costs and operating efficiencies of alternative piece8 of equipment. The methodology will assist manager8 in collecting and comparing those aspect8 of an equipment decision which can be quantified. Since managers will have an accurate estimate of the cost difference8 between alternative machines, they will be better able to judge the importance of factor8 which cannot be quantified such as safety, operator comfort, and equipment flexibility,

The emphasis of this paper will be on using the financial analysis information in selection and replacement decisions. The first section of the paper will explain the basic methodology of the approach. The second section will present an example calculation and third will be a discussion of the use8 of the result8 of the methodology.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta. GA.Nov. 6-7, 1982. Alabama Agricultural Experiment Station Journal Series.

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ANNUAL EQUIVALENT COST

There are several method8 of evaluating equipment alternatives. Most are either bared on machine rate8 or on discounted cash flow methods. All of the method8 generally consider costs such a8 accounting depreciation, capital or investment, operating, replacement, and obsolescence. The discounted cash flow method8 also allow for the inclusion of the time value of money, which is 80 important in the88 days of high interest rates, and the effect of income taxes.

The technique that I will present today is a discounted cash flow method which calculate6 and compare8 Annual Equivalent Costs (AEC's) (Smith 1973). A more detailed explanation of this technique can be found in an article by Tuft8 and Mill8 (1982). It involve8 the calculation of AEC's for every practical life length of the equipment. For example, if a machine can be expected to last 4 year8 before it must be retired, then four separate AEC's must be calculated, one for each practical life length. AEC's are calculated for all equipment alternative8 and the minimum AEC for each alternative is found. The alternative with the lowest AEC is preferred.

Unlike the machine rate methods, the ARC approach averages the cost of a machine while accounting for the time value of money. It also allow8 the decision maker to compare investments that have unequal live8 (Grant and Ireson, 1970) with the implicit assumption that the investment *could* be duplicated again and again until the investment live8 were equal.

Since revenues are usually associated with a production system not a single piece of equipment, the decision criterion for this analysis is to find the alternative with lowest cost. Costs for the alternatives should be based on the required production rate of the system, not the capability of the machine. Therefore. the output of the system and the equipment being examined are assumed fixed.

The basic equation to calculate the **AEC's** is:

$$AEC_i = \left[\sum_{i=0}^{n} c_i \; \frac{1}{(1+r)^i}\right] \left[\frac{r(1+r)^n}{(1+r)^n-1}\right]$$

where AEC_i = Annual Equivalent Cost of equipment for year i, (i=1 to n)

C_i = after tax net cost in year i,
r = alternative rate of return,
n = last year the machine is employed (n=1 to physical life limit).
$\frac{1}{(1+r)^n}$ = single payment present value factor which is simply a discount factor to convert cash flows in year i to a present value at the beginning of year 1 (i=0, and
$\frac{r(1+r)^n}{(1+r)^n-1}$ = capital recovery factor which is **a factor** that finds the equivalent uniform payment having the same present value as the actual cash flows.

The most difficult part of a replacement analysis is estimating future costs. This requires accurate records and good judgement. For this procedure. these estimates should be in nominal dollars which are the dollar prices that are actually observed in the market place in the year in which they occur. Since taxes are levied on nominal dollars, the use of constant dollars (effect of inflation removed) would complicate the accurate calculation of tax impacts.

The discussion of costs will be divided into three parts - capital investment costs **(CIC)**, operating expenses **(OE)**, and downtime, replacement and **obsolescences** costs. A more detail explanation of each of these is presented by Tufts and Mills (1982).

The capital investment costs **(CIC)** are not as obvious as operating expenses, but are usually more significant. The physical depreciation of the machine is measured by the difference between the purchase price **(PP)** and its salvage value **(SV)** when removed from service. By netting the present value of the purchase price and the present value of the salvage value adjusted for tax impacts, the opportunity cost of capital is automatically incorporated in the AEC calculation. The actual estimation of CIC after taxes requires a detailed examination of purchase price. salvage values, accounting depreciation **(D)**, book value **(BV)**, investment credits **(IC)**, investment credit recapture **(ICR)**, gain (loss) on the sale of the machine **(GOS)**, and their tax impacts.

Operating expenses include all the ordinary and necessary costs incurred in conducting an operation (insurance, property **taxes**, fuel and lubrication, maintenance and repair. and labor) and may be deducted from taxable income. After tax operating expenses are equal to the before tax operating expenses times one minus the marginal tax rate.

Downtime costs are indirect costs of machine failure as a result of stopping the entire production system. The direct costs of machine failure are incorporated in operating expenses. The organization and management of the production system determines the extent of downtime costs. If a small stockpile of work is not maintained between operations (hot logging) anytime a piece of equipment is inoperable all subsequent operations are forced to become idle. This would create an artificially high cost of downtime. The effect is less pronounced if there are multiple machines performing the same function. Likewise, since simultaneous equipment failures occur very infrequently, if there is a small stockpile between operations (cold logging). an equipment failure will not cause all subsequent operations to shut down.

Replacement and obsolescence costs are used in the cumulative cost per hour replacement models (Caterpillar 1965. Conway 1976). Replacement costs are used to estimate the increase in the purchase price of a new machine over the present machine. Obsolescence costs are charged to account for the future development of improved. more productive, cost efficient machines. In this analysis, the comparison of the least cost. most productive currently available machines adequately incorporates both the replacement cost and the obsolescence cost.

EXAMPLE CALCULATIONS

The calculation of the **AEC's** can be completed using the following six steps and by examining Table 1.

Step 1 -- List the Before Tax Cash Flows **(BTCFs)**
Dividing **BTCFs** into two categories reduces the necessary calculations. **One** category includes those costs that occur regardless of whether the machine is retained in service or sold (Totall). The second category includes costs which occur if the machine is sold at the end of any given year (Totalp).

Step 2 -- Calculate the After Tax Cash Flows **(ATCFs)**
ATCF= BTCF * TAF
where TAF = Tax Adjustment Factor, given in Table 1.

Step 3 -- Sum the ATCFs by categories.

Step 4 -- Calculate the Present Value (W) for each of the **sumed ATCFs** by categories.

$$PV = \sum_{i=0}^{n} Total_1 (i) \left[\frac{1}{(1+r)^i}\right]$$

$$PV = Total_2 (n) \left[\frac{1}{(1+r)^n}\right]$$

Step 5 -- Sum the appropriate We to obtain Net Present Values (NW) for each year of the machines useful life.

$$NPV(n) = \sum_{i=0}^{n} Total_1(i) \left[\frac{1}{(1+r)^i}\right] + Total_2(n) \left[\frac{1}{(1+r)^n}\right]$$

II-

Step 6 -- **AEC(n)** = **NPV(n)** x **CRF**

$CRF = \frac{r(1+r)^n}{(1+r)^n-1}$, the capital recovery factor.

The following example is provided to illustrate the procedure. The analysis is of a 3 year old grapple skidder. operating in a well managed. balanced system **that** requires 1.650 productive machine hours **(PMH)** of operation per year. The logging system maintains sufficient stockpiles between operations to eliminate downtime cost. The system is owned by a corporation with a marginal ordinary tax rate of 46 percent and with a cost of capital of 12 percent.

Step 1 -- list **BTCF's**
First. it is necessary to estimate before tax cash flows for the variables needed in the analysis. The 3-year old grapple skidder was purchased for $45.000 and expected values for availability. utilization. scheduled machine hours **(SMH),** productive machine hours. salvage value. accounting depreciation. and book value for its remaining life are shown in Table 2. When purchased it was set up on a double declining balance depreciation schedule for a useful life of 6 years and an investment credit was claimed. As the skidder ages, its total production decreases because of decreased availability, but its productive rate is unaffected. Due to the decrease in availability. the machine must be scheduled to work longer hours.

The estimated annual operating expenses for the skidder are listed in Table 3. These annual expenses were developed by consulting an equipment manager with many years of experience with logging equipment. They are, however. general in nature and do not represent any particular model.

Step 2 -- BTCF * TAF = ATCF
The tax adjustment factors were given in Table 1 and the after tax cash flow is simply the product of the before tax cash flow and the tax adjustment factor.

Step 3 -- Sum **ATCF's**
Totall (i) and Total2 (n) for each year were determined.

Step 4 -- Discount **ATCF's** to **PV's**
Present values were calculated by multiplying the after tax cash flow of Totall (i) and Total2 **(n)** by the single payment present value factor. The present value of the **$Total_1$** (i) was carried across to each appropriate column.

Step 5 -- Totals = NPV
Then the numbers in each column were summed to produce a net present value.

Step 6 -- NW * **CRF** = AEC

The net present value was multiplied by a capital recovery factor to calculate the AEC.

Table 4 shows the cash flows* present values, and annual equivalent costs for keeping the skidder in service. The **AEC's** for **1,** 2, and 3 years are **$29,520,** $24,451, and $23,990. respectively. Since the minimum is **$23,990,** the most economical life for the skidder would be 3 years, and the annual cost would be $23,990.

Table 1. Suggested format for calculating annual equivalent costs.

YEAR	ITEM	BEFORE TAX CASH FLOW (BTCF)	TAX ADJUSTMENT FACTOR (TAF)	AFTER TAE CASH FLOE (ATCF)	PRESENT VALUE (PV)	POSSIBLE LIFE LENGTHS (1 to n)
0	Purchase Price		1.0			
	Salvage Value					
1 to n	Investment credit		1.0			
	Depreciation		t			
	Operating Expenses		1.0-t			
	Total1 (i)			(These values to be filled in by those making the calculations.)		
n	Book Value		1.0			
	Gains on sale		1.0-t			
	Investment tax recapture		1.0			
	Total2 (n)					
	Net present value					
	AEC(n)					

Table 2. Availability, utilization, scheduled machine hours productive machine hours, salvage values, depreciation, and book values for the remaining possible life of the defender.

YEAR	1	2	3
Availability (%)	85	80	75
Utilization (%)	76.5	72.0	67.5
Scheduled machine hours	2,157	2.292	2,444
Productive machine hours	1,650	1,650	1.650
Salvage value ($)	14,100	10,700	9,000
Depreciation ($)	4,335	0	0
Book value ($)	9.000	9,000	9,000

Table 3. Estimated annual operating expenses (before taxes) for a three year old grapple skidder.

Year	Fuel and lubrication	Repair and maintenance (rebuild)	Labor	Insurance	Total Operating expenees
			($)		
1	7.623	14.200	14.531	965	37,319
2	8.662	5.700	16,798	705	31.865
3	10,395	8,100	19.462	535	38.492

Table 4. Cash flows, present values, and annual equivalent costs for a three year old grapple skidder if continued in service for 3 years.

YEAR	ITEM[1/]	BTCF ($)	TAF	ATCF ($)	PV ($)	1 YEAR ($)	2 YEARS ($)	3 YEARS ($)
0	SV	-19,300[2/]	1.0	-19,300	-19,300	-19.300	-19.300	-19.300
1	D	4,335	0.46	1,994				
	OE	-37,319	1.0-0.46	-20,152				
	Total1(1)			-18,156	-16,213	-16,213	-16,213	-16,213
	If sold:							
	BV	9.000	1.0	9,000				
	GOS	5.100	1.0-0.46	2,754				
	ICR	- 1,500	1.0	-1,500				
	Total2(1)			-10,254	9,155	9,155		
	Net PV					-26,358		
	AEC (1)					-29,520		
2	D	0	0.46	0				
	OE	-31,865	1.0-0.46	-17,207				
	Total1(2)			-17,207	-13,717		-13,717	-13,717
	If sold:							
	BV	9.000	1.0	9,000				
	GO8	1,700	1.0-0.46	918				
	ICR	0	1.0	0				
	Total2(2)			9,918	7,907		7,907	
	Net PV						-41,323	
	AEC (2)						-24.151	
3	D		0.46	0				
	OE	-38,892	1.0-0.46	-20,786				
	Total1(3)			-20,786	-14,795			-14.795
	If sold:							
	BV	9,000	1.0	9,000				
	GOS	0	1.0-0.46	0				
	ICR	0	1.0	0				
	Total2(3)			9,000	6,406			6,406
	Net PV							-57,619
	AEC (3)							23,990

1/ BV = salvage value. D = depreciation, OE = operating expenses, BV = book value, GOS = gain on sale, ICR = investment credit recapture, and PV = present value.

2/ All figures are rounded to the nearest dollar.

DECISION EARING

Now that the AEC's have been calculated, how are they used in decision making? They may be used to determine the optimal economic life of a piece of equipment. AEC's may be utilized in replacement decisions and when choosing between new models. They can also be used to determine lowest per unit cost if production requirements are variable.

The year in which the minimum AEC occurs is the optimal economic life of the equipment, in that to hold the machine for a shorter or longer time results in a higher average annual cost. If no other machine with a lower minimum cost can be found at the end of the optimal economic life, the identical machine should be purchased and held for the same period of time. The optimal economic life indicates when a piece of equipment should be replaced. The AEC's can also be used to determine the cost of deviating from the optimal economic life.

The AEC method can also be used to select the best replacement machine when it is time to replace a machine. Table 5 summarizes the AECs for the 3-year old grapple skidders and two new grapple skidders that could be used in the same well managed harvesting system with annual production of 10.000 cords. Ranked by minimum AEC from lowest to high is the old skidder. skidder B, then skidder A. Although the optimal economic lives are different, the minimum AECs can be compared directly assuming, as discussed above, that identical investments can be made again and again until a common life length is found. The selection decision between the three alternatives presented in Table 5 is to keep the old skidder for another three years.

Up to this point, production rates have been assumed fixed. However, if skidder A is 12.5% more productive and skidder production was the limiting factor in the harvesting system, the system's, annual production with skidder A could be increased to 11.250 cords. Comparing the alternatives on a cost per cord of production basis, the old skidder produces at $2.40/cd., skidder A at $2.32/cd. and skidder B at $2.43/cd. With variable production, the selection of skidder A is preferred.

One must be careful when increasing system production by introducing a more productive machine. Costs associated with other machines in the system may increase due to increased useage resulting in higher total system cost per cord, not lower cost per cord. Also AEC are generally calculated based on a given production rate because repair frequency. labor cost and other variable costs are a function of production level. Therefore. it may be best to compute a set of AECs for different production levels and compare AECs directly.

Finally. this discussion has been centered around the calculation and use of AEC when making decisions about an individual machine in a system. The methodology could, also. be used to study the costs of systems of machines and to assist in determining the least cost combination of machines within a system.

Table 5. AEC's for 3-year old grapple skidder and two new grapple skidders. r = 12% and t = 0.46.

YEARS	3 - ear old kidder	C ($) Skidder A	% Skidder B
1	-29,520 .01	-28.305.42	-25,907.04
2	-24.450.94	-26.824.37	-24.586.58
3	-23,989.50*	-26,327.39	-24,256.99*
4		-26.169.59	-25,279.76
5		-26 r369.99	-24,779.18
6		-26,075.57*	-24.678.94

* Optimal economic life. minimum AEC.

CONCLUSION

The financial analysis of equipment presented here has several advantages:

(1) Managers must estimate all costs and production requirements of the machine.
(2) Allows the incorporation of tax impacts.
(3) Adjusts costs for the time value of money.
(4) Allows investments of various length to be compared.
(5) Is relative simply to compute.
(6) Has many application and uses for management decision making.

With a little experience, forest managers can learn to quickly compute AECs and use them as decision aids.

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EFFECT OF LOGGING EQUIPMENT TRAFFIC ON SOIL DENSITY AND GROWTH AND SURVIVAL OF YOUNG LOBLOLLY PINE

by

B. Graeme Lockaby and Clyde G. Vidrine

Abstract.--Soil bulk densities, determined on plots representing a gradient of harvesting traffic, indicated that compaction was an average of 12% greater on former logging decks and primary skid roads as compared to non-trafficked areas. Penetrometer readings supported the bulk density results and, in addition, showed increased compaction on secondary roads and road borders as compared to control areas. This compaction was reflected in height growth reductions of 13% to 59% in five year old loblolly pine (*Pinus taeda* L.), on decks, primary roads, secondary roads, and road borders. Number of pine per plot was reduced by 31% to 91% on the same four areas. Plot means for root collar diameters also decreased but were not significantly different from those on control plots. The proportion of the harvested area involved in soil property impacts and reduced tree growth, however, appeared to be only about 1%.

(In process of review by Southern Journal of Applied Forestry.)

ECOLOGICAL AND SILVICULTURAL FACTORS ASSOCIATED WITH RAPID GROWTH OF LOBLOLLY PINE STANDS[1/]

Paul Y. Burns and S .C. Hu[2/]

Abstract .--Data from extremely rapid-growing loblolly pine plantations in the United States and foreign countries indicate that this species grows fastest in geographic regions where it is far removed from Its natural range, including South Africa, Brazil, Australia, and Hawaii. Ecological and silvicultural factors associated with this superior growth are analyzed in this paper.

INTRODUCTION

In 1963 Louisiana State University's School of Forestry and Wildlife Management began a research project called "How fast can a loblolly pine plantation grow?" An excellent site was selected near Bogalusa, Louisiana, the site was intensively prepared, seedlings were planted, and intensive cultural measures--weed, grass, brush, and tip-moth control; fertilization; and irrigation--were applied to encourage rapid growth. Results were spectacular in height growth; at age 11 the plot had an average height of 50.5 ft. However, the plot's volume growth was less than we had hoped although excellent by U.S. standards (2.8 cords/acre/year mean annual increment (MAI) at age 19).

Three years ago, we decided to compare our "wonder" plot with other fast-growing loblolly pine (*Pinus taeda* L.) plantations in the South and around the world. Loblolly pine is commercially grown as an exotic in a number of countries, including Australia, Brazil, Argentina, Uruguay, the Republic of South Africa, New Zealand, and China. We felt that if we could determine which ecological and silvicultural factors were associated with superior growth, loblolly pine growers might be helped in silvicultural decision making. As our study progressed, we learned that at least two U.S.-based forest products corporations with subsidiaries in Brazil were interested in discovering why loblolly pine in Brazil greatly outgrows loblolly pine on their holdings in the southern U.S. We too were intrigued by this question.

DATA COLLECTION

We collected data by examining published reports and by personal communication with foresters familiar with exceptionally fast-growing loblolly pine plots. We listed a number of ecological and silvicultural factors which we thought might be significant and ascertained without great difficulty for each plot. Foresters who responded to our letters and phone calls were asked to provide these data if they could, along with growth measurements. We are grateful to all those who cooperated in providing information.

Five outstanding plots in terms of wood volume production per acre per year were selected for this report, one each in South Africa, Brazil, Australia, Hawaii, and South Carolina.

South Africa plot

Data were supplied by C.J. Schutz, Natal Forestry Research Centre, Department of Environment Affairs, Republic of South Africa, Pietermaritzburg. He furnished data for three temporary plots in the Eastern Transvaal Drakensberg Escarpment area. We selected plot T155, which had the highest MAI at age 20. The nearest weather station is at Witklip.

Brazil plot

McDavid Hughes, Manville Forest Products Corporation, West Monroe, Louisiana, and J.P. McTague, Manville Produtos Florestas Ltda., Igaras, Santa

&/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ Professor and Associate Professor, respectively, Louisiana State University School of Forestry and Wildlife Management, Baton Rouge, Louisiana 70803.

Table 1. -- Stand characteristics of loblolly pine plantation plots showing outstanding growth

Plot location	Plantation age	Original trees/ac	Living trees/ac 1/	Ave. dbh 2/	Ave. ht	Dom. ht 3/	Basal area	M.A.I. production 4/	Site index 5/
	yrs.	no.	no.	in.	ft.		$ft.^2/ac$	$ft.^3/ac/yr$	ft.
South Africa	22	809	121	13.63	---	99	123	523	107
Brazil	8	947	852	7.33	35	40	250	442	89
Australia	16	703	346	8.70	---	56	142	382	76
Hawaii	11	1,210	1,150	6.66	38	42	278	371	78
So. Carolina	11	908	639	7.43	49	54	193	352	95

1/ Brazil, Hawaii, and So. Carolina plots were unthinned; South Africa plot was thinned at ages 9,12,14,17, and 21; Australia plot was thinned at age 15 years, 9 months.

2/ Average dbh is quadratic mean.

3/ Dominant height is the average height of dominants and codominants (for the South Africa and Australia plots, derived from top height and predominant height, respectively).

4/ Mean Annual Increment, production is total i.b. all trees, standing volume plus thinning volumes, divided by plantation age, except for South Africa, where it is based on age 20.

5/ Site index is based on dominant height at age 25; it was computed from equation (2), southwide parameters, in an article loblolly site index by *Golden et al.* (1981).

Catarina, Brazil, furnished data for a temporary plot on the Rio do Tigre Farm near Igaras. In addition, we obtained valuable growth information on loblolly pine in Brazil from D.M. Crutchfield, Timberlands Division, Westvaco, Summerville, South Carolina.

Australia plot

For the Australia plot data, we are indebted to D.I. Bevege, Forestry Commission of N.S.W., Beecroft, New South Wales, and Alan Harvey, Queensland Department of Forestry, Brisbane. The plot is located near Crohamhurst, Queensland. Dr. Bevege sent data on seven fast-growing permanent plots; we selected the one with the highest MAI.

Hawaii plot

Data for the Hawaii plot were contained in a publication (Whitesell 1974); Craig Whitesell *gave* us additional information by personal communication, and the senior author (Burns) visited the plot in 1980. The plot selected was the fastest growing in a spacing trial on Maui Island, near Olinda.

South Carolina plot

To our knowledge the most rapid growth on record for loblolly pine in the South is described by Langdon et al. (1970). We used data in their article, supplemented by telephone conversations with W.P. LeGrande, Santee Experimental Forest, and W.R. Harms, U.S. Forest Service, Charleston, South Carolina. The plantation was established on Wadmalaw Island, about 10 miles southwest of Charleston.

RESULTS AND DISCUSSION

Several problems were encountered in presenting stand data on a comparable basis. Within the world forestry community and even in the U.S. there is no standard method of stand description. Plantation age in the U.S. is commonly expressed to the nearest year; in Australia and South Africa it is often expressed to the nearest month. Average dbh is commonly, but not always, shown as the quadratic mean. Stand height as reported for site index determination is usually expressed in the U.S. as dominant height, in South Africa as top height, and in Queensland as predominant height. Volumes may be presented inside *or under* bark, sometimes outside or over bark; merchantable limits vary considerably.

Although outside the U.S. the metric system is fairly standard, this paper is being presented to U.S. foresters, so we used the English system. Data sent to us from other countries were converted to this system. Where a stand characteristic which we wanted to present was not provided in the data available to us, we made a reasonable approximation.

The volume unit we chose is total entire stem inside bark. Since the plots differed in age, we compared the plots as to rate of dominant height growth by computing site indices, base age 25, with a formula by Golden et al. (1981).

Stand growth characteristics of the five plots are shown in table 1. Growth in comparison with most loblolly pine plantations in the southern U.S. is phenomenal for all five plots, ranging from a MAI of 352 ft^3/acre/year for the South Carolina plot to 523 for the South Africa plot. Site indices are also very high, ranging from 76 for the Australia plot to 107 for the South Africa plot.

By comparison, well-stocked loblolly pine plantations in the U.S. at age 20 normally average about 188 ft^3/acre/year, with a range from 80 to 300; site indices average about 60, ranging from 40 to 80.

The plot with the highest MAI (523) is South Africa's. However, it is older than the other plots, and at age 20 it is probably at or near its maximum MAI. Just how long the Brazil plot will continue its rapid growth is not known; extensive planting of loblolly pine in Brazil began only about 16 years ago (Sedjo 1980). Machado (1978) stated that loblolly pine plantations in the central region of Parana (the state north of Santa Catarina) grow very rapidly for the first 10 to 13 years, but this growth is followed by a fast decline, at least in dense stands. However, J.P. McTague told us this year that loblolly pine at Igaras, some of which is 18 years old, has continued its rapid growth. Production MAI in the Brazil plot, now 8 years old, thus seems likely to reach 500 to 600 ft^3/acre per year by age 20, thus making its growth comparable with the South Africa plot. We estimate that production MAI in the other three plots will reach 400 to 500 ft^3/acre/year by age 20.

It is worthy of note that the site indices of the Australia and Hawaii plots, although high, are below 80, indicating that their remarkable volume growths are perhaps more a result of extremely high basal area production than of good height growth. The basal area of the unthinned Hawaii plot was 278 ft^2/acre at age 11; the Australia plot achieved a basal area production, including thinnings, of 260 ft^2/acre/year at age 16. The conventional site index in forestry is based on height growth; however, it may often be the case that basal area growth does not respond to the same ecological factors as does height growth. Thus a plot's height growth may result in a site-index classification which seriously underestimates or overestimates the plot's volume production.

Topographic and climatic factors

The results (table 2) indicate that loblolly pine can grow quite well at latitudes varying from about 21° to 33° depending to some extent on the elevation above sea level and other factors. Latitude has an effect on the length of daylight during the growing season (days are longer in higher latitudes) and on the intensity of light during the growing season. It is noteworthy that the four fastest growing plots are more than 590 feet above sea level in elevation, indicating that prrhapa elevation is a "plus" in stimulating growth.

Topographic positions varied for these plots from moist lowlands to a plateau and including middle slopes. Hawaii's and Australia's plots have aspects that tend to mitigate soil moisture loss.

The climate of all five plots is humid subtropical, characterized by mild winter temperatures, moderately warm summer temperatures, and abundant rainfall, particularly during the six-month warm season.

The average freeze-free period is a crude measure of length of growing season, and we expected a high correlation with growth. Four locations had very long freeze-free periods (more than 290 days). The considerably shorter freeze-free period, 210 days, at the Brazil plot seems to be an anomaly. This freeze-free period length is characteristic of western Tennessee, north of the area of rapid loblolly pine growth in the U.S. It may be the case (data are not available to us) that the actual growing season for loblolly pine is considerably longer than 210 days at the Brazil site, particularly if this area has short, sporadic frosts during the warm season.

Average annual rainfall varies from a low of 52 inches at the South Carolina plot to 74 inches at the Australia plot. Warm-season rainfall exceeds 32 inches at the four plots for which data are available. Loblolly pine grows best where warm-season rainfall is abundant. Shoulders and Tiarks (1980), in their study of southern pine plantation height growth in the Gulf Coastal Plain, found that April-through-September rainfall at loblolly pine sites averaged 31 inches, ranging from 24 to 46.

Fog is a significant growth factor for some forest stands. For example, soil moisture may be added by fog drip from trees. The South Carolina plot has a fairly high incidence of warm-season fog. As best we could determine, the other four plots are not significantly affected by fog.

A loblolly pine stand which is probably favorably influenced by fog or mist is located in the Southern Cape area of South Africa (latitude 34° S). Data supplied by F. Beekman, Saasveld Forestry Research Station, George, showed that this plot had a high MAI (500 ft^3/acre/year at age 20) with warm-season rainfall only 25 inches. However, mist in summer is common at this site.

Table 2.--Topographic and climatic factors, loblolly pine plots showing outstanding growth

Plot location	Latitude	Elev. above sea-lev.	Topog.	Slope % & aspect	Freeze free period[1]	Normal winter temp.[2]	Normal summer temp.[3]	Ave. ann. pptn.	Warm season pptn[4]	Warm season R.H.[5]	Ann. water def.[6]
		ft.			days	deg. F	deg. F		in.	percent	in.
So. Afr.	24°54'S	2,871	Alluvial fl. plain	0	300	55	66	63	52	---	---
Brazil	27°30'S	2,790	Lower slope, plateau	5-10	210	54	73	59	34	79	0.0
Austral.	26°49'S	592	Middle slope	7 SSE	365	55	74	74	51	78	---
Hawaii	20°49'N	3,740	Middle slope	10-15 NW	365	54	60	54	---	---	---
So. Car.	32°43'N	12	First terr. Coast. Pl.	O-l	294	49	80	52	32	71	0.3

1/ Freeze-free period is the average number of days between dates of the last spring minimum and the first fall minimum of 32° F or below.

2/ Normal winter temperature is the normal daily average for January (No. Hemisphere) or July (So. Hemisphere).

3/ Normal summer temperature is the normal daily average for July (No. Hemisphere) or January (So. Hemisphere).

4/ Warm season precipitation is the average total for the 6-month period April-September (No. Hemisphere) or October-March (So. Hemisphere).

5/ Warm season relative humidity (R.H.) is the average for the warm season defined above.

6/ Mean annual water deficit is potential evapotranspiration - actual evapotranspiration. Mean annual potential evapotranspiration was computed by Thornthwaite's method, 12 in. moisture in a rooting zone of 6 ft.

Warm-season relative humidity is high in the three plots for which this climatic statistic was provided.

Mean annual potential evapotranspiration is and expression of tree needs for water; it is calculated empirically from air temperatures without regard to soil differences. When soil moisture is low, actual evapotranspiration is below potential, and a deficit occurs. Unfortunately, water deficit data are available for only two of the plots--Brazil and South Carolina. The fact that the mean annual deficit is close to zero for these two plots is probably significant in causing their rapid growth. In view of the high warm-season rainfall and relatively low summer temperatures at the South Africa and Australia sites it seems likely that the mean annual water deficit of these plots is also near zero.

Geologic and soil factors

A variety of parent materials ranging from sedimentary (several sources) to volcanic ash is represented in our data (table 3). Soil classifications also vary considerably, and no definite conclusions have been drawn.

Soils of the five plots appear to be excellent for loblolly pine growth. Topsoils are loamy, subsoils have favorable texture, and all soils are deep. Soil structure is an important factor in tree growth; however, we were unable to get information on this attribute, except for the South Africa plot, which has a porous soil, and the Hawaii plot, which has moderately rapid permeability and a subangular

Table 3.--Geologic and soil factors, loblolly pine plots showing outstanding growth

Plot location	Parent material	Soil classification 1/	Topsoil Texture	Topsoil Depth	Topsoil pH	Subsoil Texture	Subsoil pH	Total soil depth	Water table depth	Surface drainage	Internal drainage
				in.				in	ft.		
So. Afr.	Granite alluvium	Inceptisols	Sandy clay loam	9	---	Sandy clay	---	59+	8	Good	Good
Brazil	Sedimentary on basalt	Passa dois rio do rasto	Silt loam	16-18	5.2	Silt	---	40+	l-6 shallow winter	Fair	Fair
Austral.	Tertiary basalt	Dystric Nitosols, Lateritic Krasnosem	Loam	20	5.7	Loam to clay loam	5.4	36+	Deep	Good	Good
Hawaii	Volcanic ash over andesite or basalt	Inceptisols, Dystrandepts, Entic, Medial Isomesic Olinda	Loam	6	6.2 to 6.4	Silty clay loam	6.2 to 6.4	42	Deep	Good	Good
So. Car.	Sandy marine sediments	Entisols, Udipsamments Aquic, mixed Thermic Seabrook	Loamy fine sand	appr. 12	---	---	---	48+	2-6	Poor	Good

1/ Soil classification for Hawaii and So. Carolina is'based on U.S. S.C.S. system (Soil Survey Staff 1975); South Africa series is "Oakleaf Jozini;" Brazil classification is local name; Australia classification is based on FAO-UNESCO (1974) Soil map of the world, 1:5,000,000, Volume I, Legend, p. 19.

blocky subsoil structure. Soil pH where recorded is acid and favorable for loblolly pine, ranging from 5.2 to 6.4.

At the South Africa, Brazil, and South Carolina plots, water tables may be accessible to tree roots, thereby stimulating rapid growth. However, rainfall is abundant at these sites, and the water table may not be a growth factor.

Detailed soil information is available for a loblolly pine plot (No. 7-10-3) in Brazil, located on Rigesa Woodlands of Westvaco, in Santa Catarina some distance north of Igaras. Located at the bottom of a 10 percent slope, at age 8 the plot's MAI was 429 ft^3/acre/year. Dominant height was 50 feet, yielding a site index estimate of 104 feet based on Golden et al.'s equation. The soil is very deep--more than 96 inches. The topsoil is a friable clay loam, subsoil friable granular clay. Topsoil bulk density is 0.895 g/cm^3, indicating favorable structure. Soil pH is 4.3 to 4.5, and the C:N ratio is high--8.3 in the A horizon and 10.0 in the B--conducive to good growth. Silt-plus-clay content (fines) is 57 percent in both horizons. Climatic data for this plot are not available, but the soil data are valuable in understanding the excellent growth rates of loblolly pine in Brazil.

Detailed nutrient status information is unavailable for our five plots. Subjective judgments indicate that soil nutrients are adequate for good growth.

In forest stands the presence or absence of soil pathogens (nematodes, viruses, fungi, and bacteria) is not easily detected unless tree mortality is abnormal. It is not surprising that there is limited information on this factor in our data. Low populations are reported for the Brazil and Australia plots; no data on soil pathogens are available for the others. The high wood production of all five plots indicates that soil

Table 4.--Silvicultural factors, loblolly Pine plots showing outstanding growth

Plot location	Geogr. source seed	Pheno-type parent	Age of seedl.	Replace-ment planting	Former use of site	Site prepa-ration	Fertilizer applied	Weed & grass control	Brush control
So. Afr.	Local	---	1-0	---	Grass pasture	1 m^2 plntng spots scalped hoed in center	None	First yr.	Not Needed
Brazil	So. Ga. No. Fla. Cent. Ala.	---	1-0	Yes	Parana pine - hardwds	Bull-dozed K-G blade	None	None	First 3 yrs.
Austral.	Ocala Fla.	Local plus trees	1-o	No	Rain-forest cleared, grazed	Planted directly on pasture	None	None	Not needed
Hawaii	---	---	1-1	Yes	Grass pasture	Grazed heavily, plntng spots scalped	None	None	Not needed
So. Car.	Local	Seed prod. area	1-o	No	Old field farmed yr. bef. plntg.	Bedding	None	First yr.	Not needed

pathogens, if present, are not causing appreciable mortality. However, nematodes probably have significance in tree disease considerably in excess of current scientific knowledge, and these organisms have received scant attention in forest soil studies. It seems quite possible that some of our observed growth differences in these five plots are related to differences in soil pathogen populations.

Silvicultural factors

For the Australia plot, planting spacing (table 1) was perhaps a little too open (703 trees/acre) for maximum total-stem volume production. Original spacing varied from 809 to 1,210 seedlings per acre in the other four plots, close enough for maximum *or* nearly maximum total-stem volume production.

Several other *silvicultural* factors that may be associated with the growth of these stands are listed in table 4.

None of the five plots was planted with seedlings of proven genetic superiority. Additional loblolly pine growth data from the Eastern Transvaal, supplied by N.P. Denison, Mondi Timber, Sabie, show that genetic factors are important. MA1 (ages varying from 12 to 20 years) from a seed-source study with 15 seed origins varied from 182 to 396 ft^3/acre/year. The genotypes of our five plots are not known. Therefore it is nearly impossible to assess the importance of genetic factors in their growth.

Although the Hawaii plot was planted with 1-1 rather than with 1-O stock, this seemingly was not significant in causing its excellent growth, although it may have helped in minimizing the need for weed and grass control in the plot's early years.

Replacement planting was used in the Brazil and Hawaii plots, but it is unlikely that this practice caused their rapid growth.

In the U.S., old-field sites on the average produce faster-growing pines that cutover forest sites, perhaps because of more favorable soil conditions, Four of our five plots had been in pasture or farm crops before planting; the Brazil site had been in native forest,

Site preparation was used on all plots except the Australia plot. None of the plots was fertilized nor irrigated. Water control in the wet-site South Carolina plot was accomplished by bedding.

Weed and grass control was done only on the South Africa and South Carolina plots. The generally excellent growth of loblolly pine on good sites in South Africa may in part be due to the weed-control practices reported by Darrow (1979). The Brazil site, cutover forest, probably.had few herbs and grasses; it received needed brush control. The fast growth of the Australia plot is a little surprising in view of the lack of weed and grass control.

It is unlikely that the thinning (table 1) and the artificial pruning which were applied to the South Africa and Australia stands had a significant effect on stand production, since MAI was expressed in total-stem volume rather than in merchantable volume.

To date, loblolly pines in South Africa, Brazil, Australia, and Hawaii have been remarkably free of disease and insect attacks, although ant control was needed the first year in the Brazil plot. Fusiform rust and tip-moth attacks, common in the southern U.S., do not occur where loblolly pine is far removed from its natural range. Recently a strange decline of tree crowns in some 40- to 50-year-old loblolly pine stands in the Eastern Transvaal was reported (Schutz and Wingfield 1979); however, this disease did not occur on our South Africa plot. Fusiform rust and tip-moth attacks probably did affect the growth to some extent in the South Carolina plantation, but these factors were apparently of minor significance; they were not mentioned in Langdon et al.'s (1970) article. It is difficult to estimate the importance of the apparently complete lack of insect and fungal damage on the growth of the four fastest growing plots in our study.

CONCLUSIONS

Loblolly pine plantations are capable of high wood production, up to at least 352 ft^3/acre/year in the southern U.S. and 523 ft^3/acre/year in areas where it is an exotic. Generally this species grows fastest in geographic regions where it is far removed from its natural range, including South Africa, Brazil, Australia, and at least one mountain-side site in Hawaii. The best sites in South Africa and Brazil produce faster growth of this species than the best areas in Australia.

Loblolly pine can grow rapidly at latitudes varying from 21° to 34°. At tropical latitudes, an elevation which is several thousand feet above sea level may be required. Plateaus, floodplains, and gentle middle slopes are suitable.

Climatic factors associated with superior loblolly pine growth generally include a long freeze-free period, mild wet winters, and warm to moderately warm wet growing seasons. Fog or mist may provide additional needed moisture to some sites. Soil water deficits averaging near zero appear to be beneficial.

Fast-growing loblolly pine apparently requires a deep, internally well-drained acid soil; loamy topsoil; clay, silt loam, or clay loam subsoil; and a favorable supply of soil nutrients. On some sites a water table within reach of tree roots is an asset. Soil pathogens are a largely unstudied and unknown factor.

Outstanding growth can be achieved on cutover forest sites as well as old fields or pastures. Seedlings need not be of proven genetic superiority, although seed source is important. Fertilization is not necessary for rapid growth if soil nutrients are abundant. Weed, grass, and brush control may be helpful in some stands. Disease and insect control measures, except for ant control in Brazil, are not necessary in the locations which we studied. Loblolly pines are remarkably healthy in these locations.

We are unable to draw definite conclusions as to why loblolly pine generally grows faster in South Africa, Brazil, and Australia than it does in the southern U.S. We surmise that loblolly pine grows faster as an exotic in the subtropics because of (1) abundant and well-distributed rainfall, (2) high humidity, (3) a long growing season, (4) good soils, (5) lack of serious pests, and (6) moderately intensive silvicultural practices.

Because of the large number of ecological and silvicultural factors associated with loblolly pine growth, additional extensive research is needed to provide more definitive answers. Growth factors that can be controlled should be held constant; factors that cannot be controlled should be carefully measured. A series of internationally coordinated experiments should be initiated,

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EFFECTS OF THINNING AND FERTILIZATION ON GROWTH OF UPLAND OAK STANDS IN THE BOSTON MOUNTAINS OF ARKANSAS: 7-YEAR RESULTS[1/]

David L. Graney[2/]

Abstract.--A study of thinning and fertilization of 50-year-old northern red oak (Quercus rubra L.), black oak (Q. velutina Lam.), and white oak (Q. alba L.) was initiated in the Boston Mountains of Arkansas in the spring of 1975. Fertilizer applications of a nitrogen and phosphorous combination were broadcast at two levels to individual oaks that had received thinning or nonthinning treatments. Both levels of fertilization increased diameter growth of all oaks in thinned and nonthinned stands, and thinning further increased this response. Maximum response to fertilization occurred during the first and second years after treatment. Response continued through the fourth year for the lower level of nitrogen and through the fifth year for the higher level. A significant diameter growth response to thinning occurred during the third growing season after treatment for red and black oaks and the fifth growing season for white oak.

INTRODUCTION

Several hundred thousand acres of forest land in northern Arkansas support overstocked, even-aged, pole-sized stands of oaks and associated species. Although many stands are on medium to good sites (site index of 60 to 70 feet at 50 years), diameter growth averages only about 1 inch in 10 years. Since there are very few markets for small diameter hardwoods there has been very little intermediate cutting in these stands. But, because demands for hardwood sawtimber are increasing and inventories of large poletimber and immature sawtimber are small, some land managers have begun noncommercial thinning programs to accelerate growth of potential crop trees. Fertilization may further stimulate growth of crop trees. Research has shown that northern red (Quercus rubra L.), black (Q. velutina Lam.), and white (Q. alba L.) oaks will respond to nitrogen (N) and phosphorous (P) fertilization. Two-year diameter growth of fertilized red oaks has been shown to increase by 45 to 70 percent and white oak about 60 percent. Red oaks responded more to higher levels of N, but white oak proaucea about the same response to medium and higher levels of N (Graney and Pope 1978a, 1978b). This paper summarizes 7-year growth responses of red oaks (northern red and black oaks) and white oak in the Boston Mountains of Arkansas. Objectives were to determine how fertilizer applications affected diameter growth in thinned and nonthinned stands and to determine the effect of thinning on diameter growth response to fertilization.

METHODS

Study Area

The Boston Mountains are the highest and southernmost member of the Ozark Plateaus physiographic province (fig. 1). They form a band 30 to 40 miles wide and 200 miles long from north central Arkansas westward into eastern Oklahoma. Elevations range from about 900 ft in the valley bottoms to 2,500 ft at the highest point. The plateau is sharply dissected, and most ridges and spurs are flat to gently rolling and generally less than one-half mile wide. Mountain slopes consist of an alternating series of steep simple slopes and gently sloping benches.

Rocks in the area are sedimentary and predominantly of Pennsylvania age, consisting of alternating horizontal beds of shale and resistant sandstone. Annual precipitation averages 46 to 48 inches, with March, April, and May the wettest months. Extended summer dry periods are common,

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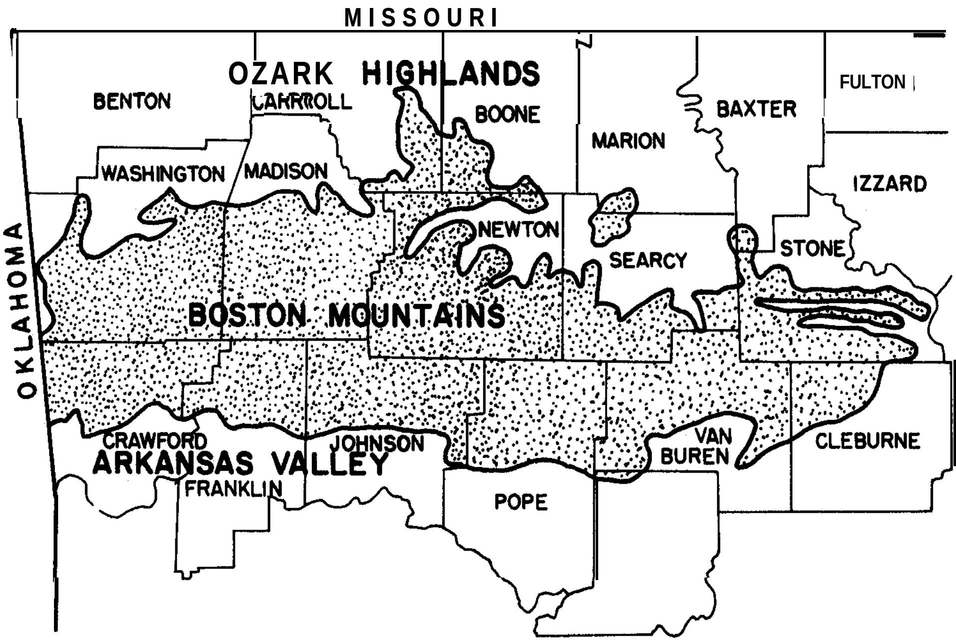

Figure 1.--The Boston Mountains in Arkansas.

and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Three study areas were selected in overstocked stands on mountain benohes that range from 2 to 3 chains wide. Soils are deep, well-drained, medium-textured members of the Nella and Leesburg series (Typic Paleudults); derived from sandstone and shale colluvium; and rated medium to high in productivity.

Sample Trees

In each area, 48 red oak and 48 white oak trees were selected for the thinning and fertilizer treatments. Trees from each species group were arranged into 16 sets of 3 trees each. Members of each 3-tree set were uniform in diameter, crown size, and height and were located on essentially the same site conditions. Thin or nonthin treatments were randomly assigned to each 3-tree set, and three fertilizer treatments were randomly assigned to trees of the thinned and nonthinned sets. In total, there were 144 red and black oaks and 144 white oaks at three locations.

Tree Measurements

Diameter at breast height (d.b.h.) of each sample tree was measured to the nearest 0.01 inch. The diameter measurement point was identified by a painted band on each tree. Increment cores, extracted from the north, east, south, and west sides of each tree, were sealed in plastic soda straws. These were used to determine tree age and to obtain a measure of past growth, Past annual radial growth was measured to the nearest 0.01 inch using a binocular microscope. Total height was also recorded for each tree.

Thinning Treatment

Basal area around each sample tree was determined with a prism. Basal area was reduced to about 70 ft^2 by removing two major competitors and several smaller trees. Thinning was completed in March, 1975. Average tree and stand characteristics at this time are shown in Table 1.

Table 1. Mean stand and tree characteristics for red and white oak thinned and nonthinned treatments at beginning of study.

Treatment	Age	Site Index	Initial Dismetqr	Basal Area
	years	feet	inches	ft^2/Acre
		BED OAKS		
Thinned	50	62	8.18	68
Nonthinned	50	62	8.48	120
		WHITE OAKS		
Thinned	52	59	8.26	66
Nonthinned	52	59	7.89	123

Fertilizer Treatments

A combination of two fertilizers, ammonium nitrate (34-0-0) and diammonium phosphate (18-46-o) was used. Fertilizer treatments were: (1) no fertilizer (nonfertilized), (2) 200 lbs N + 45 lbs P per acre (200 lb treatment), and (3) 400 lbs N + 45 lbs P per acre (400 lb treatment). Fertilizers were surface broadcast in late April, 1975, on a 0.01 acre circular plot surrounding each tree.

Data Analysis

The study design was a split-plot with thinning representing the whole plots and fertilizer treatments the subplots. Data were analyzed by analysis of covariance with mean annual diameter growth for the 5-year period prior to treatment (1970-1974) as the covariate. Differences among adjusted treatment means were tested using Duncan's multiple range test.

RESULTS

Response to Thinning

Red and white oak sample trees produced an immediate positive response to thinning and the rate of annual diameter growth generally increased throughout the 7-year period of the study (Table 2). Levels of response were greater and more apparent in the fifth through seventh years when fertilizer response declined and growth rates of nonthinned trees slowed to pretreatment levels or less.

Table 2. Mean annual diameter growth response of red and white oaks to thinning[1].

Year	RED OAKS			WHITE OAK		
	Nonthinned	Thinned		Nonthinned	Thinned	
	Growth	Growth	Response	Growth	Growth	Response
	- - - inches - - -		%	- - - inches - - -		%
	0.155	0.179				
1975	0.174	0.198	16	0.162	0.181	12
1976			14	0.176	0.198	13*[3]
1977	0.135	0.173	28**[2]	0.152	0.169	11
					0.145	1
1978	0.126	0.162	33**	0.142	0.161	13*
1981[4]	0.101	0.162	60**	0.125	0.155	24**
Mean	0.132	0.171	30**	0.145	0.166	15**

1/ Data averaged over all fertilizer rates and adjusted for differences in diameter growth using the 5-year period before thinning.

2/ Percent increase of thinned over nonthinned.

3/ Statistically significant; * =P < .05; ** =P < .01

4/ Mean annual growth for 1980 and 1981.

Diameter growth rates of thinned red oaks were significantly greater than rates of nonthinned trees from the third through the seventh year and averaged a 60 percent increase for the sixth and seventh years. Over the 7-year period, thinning increased red oak diameter growth by about 30 percent.

White oak responded positively to thinning, but the level of response was lower than observed for the red oaks (Table 2). Differences in diameter growth between thinned and nonthinned white oaks were at or near significant levels for 6 of the 7 years, and growth of thinned trees averaged about 24 percent greater than nonthinned trees for the sixth and seventh years. Although initial response of white oak to thinning was small, differences between thinned and nonthinned trees should increase over the next several years. Annual diameter growth of thinned and nonfertilized white oaks were continuing to increase through 1981 while nonthinned and nonfertilized trees were continuing to grow at pretreatment levels (fig. 2). Growth will probably decline as crowding and competition increase in the overstocked stands. The same general pattern of response is also indicated for the red oaks.

Differences in early levels of response to thinning by red and white oaks are probably due to differences in initial crown size and competitive position in these overstocked stands. On the same site, northern red and black oaks usually average a site index 5 or more feet greater than white oak. The red oaks attain dominant crown positions and develop and maintain relatively large crowns. In overstocked stands, most white oaks occupy lower crown positions and will suffer continuous reduction in crown size due to crowding, but will persist for many years with very low rates of growth. As indicated by the consistent decline in diameter growth prior to thinning (fig. 2), all trees needed release, but the red oaks were generally in better condition to respond than were white oak. Apparently, to maintain reasonably acceptable rates of diameter growth, white oak crop trees require release from crown competition earlier than red oaks and certainly before they suffer apprciable loss in crown size.

Response to Fertilization

Fertilizatiop significantly increased diameter growth of both red and white oaks over the 7-year period of the study, but the response varied between species and was influenced by the thinning treatment (Table 3).

Red oaks.--Thinned red oaks produced the greatest overall response to fertilization and were the most responsive to the higher level. Those fertilized at the 400 lb N level were the only trees to produce a significant response the sixth and seventh years after treatment.

For the 7-year period, mean diameter growth of thinned, fertilized red oaks averaged 26 percent more than growth of nonfertilized trees for the 200 lb treatment and 56 percent more for the 400 lb level. Nonthinned red oaks also responded to fertilization with increases of 32 to 36 percent over the nonfertilized trees. Nonthinned trees produced a greater response to the 400 lb treatment the first 2 years following treatment, but the response was about equal to the 200 lb treatment for the remainder of the study.

Maximum response to fertilization occurred during the first 2 years after treatment. Response declined annually, but remained significantly greater than nonfertilized trees through the fifth year. Only the thinned red oaks 400 lb treatment produced a significant response over the sixth and seventh years.

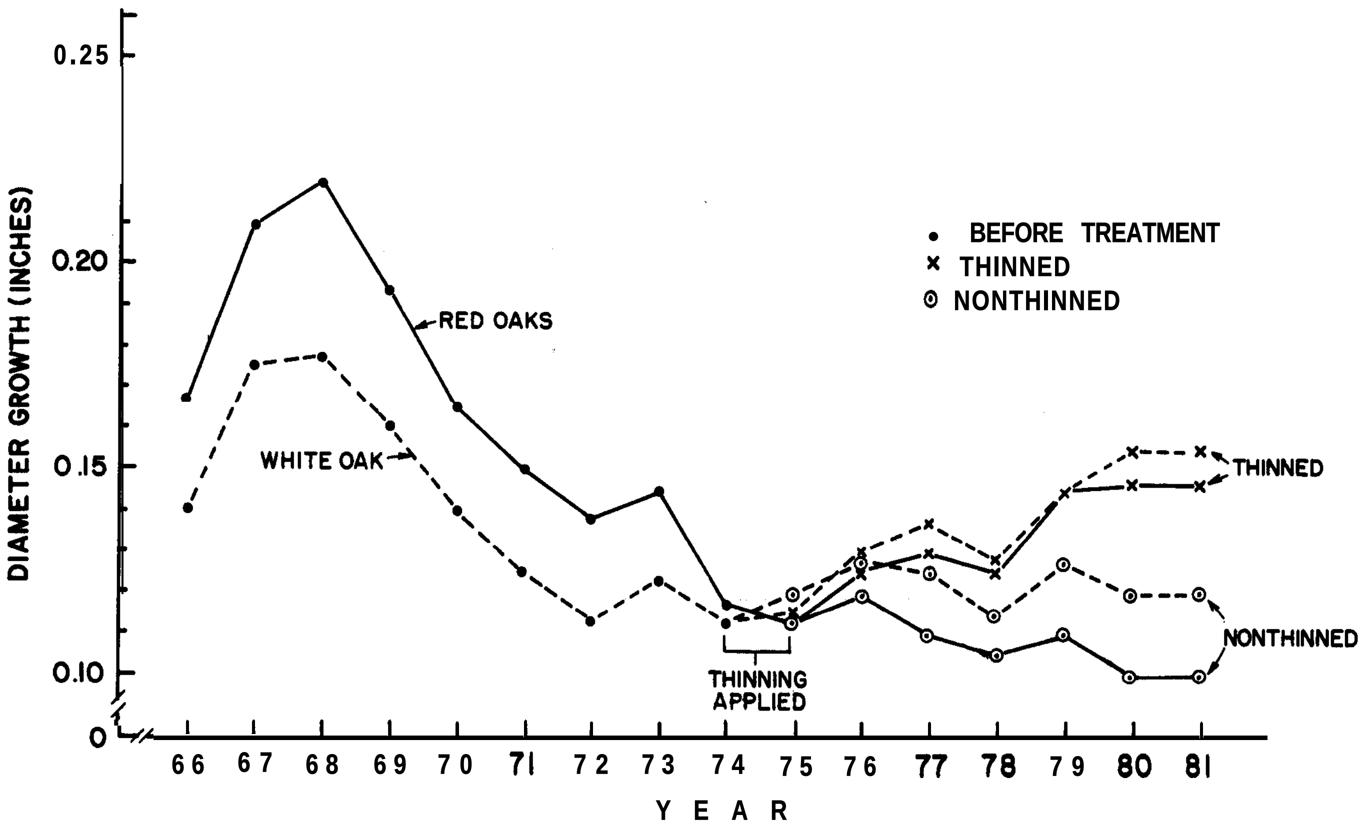

Figure 2.--Mean annual diameter growth of nonfertilized red and white oak crop trees before and after thinning,

Over the 7-year period, growth response to fertilization for thinned red oaks averaged about 40 percent, slightly lower than the response reported for northern red oak in thinned stands in New York (Karning 1972) and higher than reported for thinned black oaks in the Missouri Ozarks (watt 1974). Seven-year increases in diameter growth of nonthinned red oaks in the present study averaged 34 percent which was slightly lower than observed for red oaks in the Tennessee Valley (Farmer et al. 1970) and slightly higher than increases for northern red oak in West Virginia (Lamson 1978, 1980) and scarlet oak in Pennsylvania (Ward and Bowersox 1970).

White oak.--In contrast to red oaks, thinned white oak was much less sensitive to the two levels of N fertilization. Both produced about the same increase, 30 percent (Table 3). Thinned white oak at the 400 lb level did not produce a significant response over the 200 lb application rate until the fifth year following treatment. Conversely, nonthinned white oak responded significantly more to the 400 lb treatment than to 200 lb, and averaged a 34 percent increase over growth of nonfertilized trees over the entire 7-year period.

White oak also produced a maximum response to fertilization during the first 2 years following treatment. After the second year, response to fertilizer declined annually, but remained significant through the fifth year with thinned and nonthinned trees fertilized at the 400 lb rate producing the greatest response. Mean diameter growth for years 6 and 7 was about the same for all treatments (Table 3).

Mean 7-year response of the thinned and nonthinned trees to the fertilizer treatments was about 29 percent, nearly the same as 5-year responses reported for fertilized white oak in Pennsylvania (Ward and Bowersox 1970) but only about half of the S-year responses observed for white oak in the Tennessee Valley (Farmer et. al. 1970).

DISCUSSION

Overall response of red and white oaks to fertilization was reduced by the general lack of response during a severe drought in 1980 and the inability to recover during the very wet growing season of 1981. Growth of all study trees was affected to some extent, but nonthinned fertilized trees suffered the greatest reductions 'in growth.

Fertilized nonthinned white oak had greater diameter growth than nonfertilized trees in 1977 and 1978 but decreased to about the same level as the nonfertilized trees during the 1980-81 growing seasons (Table 3). Thinned white oak fertilized at the 400 lb level maintained the same rate of diameter growth, but were overtaken by the

Table 3. Mean annual diameter growth response to fertilization for thinned and nonthinned red and white oaks[1]

Year	Thinned					Nonthinned				
	Nonfertilized	Fertilizer Treatment 200 lb		Fertilizer Treatment 400 lb		Nonfertilized	Fertilizer Treatment 200 lb		Fertilizer Treatment 400 lb	
	Growth	Growth	Response[2]	Growth	Response	Growth	Growth	Response	Growth	Response
	--- inches ----		%	inches	%	--- inches ----		%	inches	%
					RED OAKS					
1976	0.128a[3]	0.202b	68	0.263c	102	0.120a	0.168b	47	0.185b	62
					53		0.190b	58	0.211b	76
1978	0.126a	0.148b	28	0.220c	44	0.110a	0.142b	29	0.152b	38
1979				0.182c		0.105a	0.136b	30	0.136b	30
1981[4]	0.148a	0.163a	12 7	0.177b	[illegible]	0.109a	0.138b	27	0.137b	26
							0.104	4	0.100	0
Mean	0.134a	0.169b	26	0.209c	56	0.107a	0.141b	32	0.146b	36
					WHITE OAK					
			91							
1975	0.115a	0.220b	79	0.205b	78	0.121a	0.169b	40	0.197c	63
1976	0.131a	0.234b	38	0.227b	73	0.127a	0.184b	45	0.218c	72
1977	0.137a	0.189b		0.181b	32	0.125a	0.154b	23	0.179c	43
1978	0.1278	0.150b	18	0.160b	26	0.116a	0.1358	16	0.155b	34
1979	0.144a	0.1598	10	0.180b	25	0.128a	0.1408	9		24
1981	0.156	0.156	0	0.154	-1	0.120	0.128	7	0.159b	4
Mean	0.138a	0.181b	31	0.180b	30	0.123a	0.148b	20	0.165b	34

1/ Data adjusted for differences in diameter growth during the 5-year period before treatment.
2/ Percent increase over nonfertilized treatment.
3/ Values in rows followed by the same letter are not significantly different at the 0.05 level.
4/ Mean annual diameter growth for 1980 and 1981.

nonfertilized trees which actually increased in rate of diameter growth in 1980-81. Diameter growth for nonthinned and nonfertilized white oak trees over the 11-year period 1971-81 indicates the species' ability to survive and grow in dense stands for long periods. Though generally in a less competitive crown position, subjected to intense crowding and competition, and possessing very small crowns, white oak maintained a fairly consistent rate of diameter growth over the 11-year period.

Nonthinned red oaks, on the other hand, were much more sensitive to competition and crowding and declined in diameter growth each year following the wetter-than-normal growing seasons of 1967-69. The differences in response for thinned and nonthinned red oak fertilized trees during 1980-81 suggests that effective crown release of fertilized trees may increase the duration of the growth response to fertilization. While diameter growth of nonthinned red oaks fell below the pretreatment level during 1980-81, thinned red oaks remained above this level. Thinned red oaks that had been fertilized showed a 20 percent greater growth than nonfertilized.

The 7-year results of this study indicate that diameter growth of pole-sized red and white oaks can be increased by thinning and/or fertilization. In overstocked stands, where crop trees have been subjected to extended periods of severe crowding, thinned trees will generally produce a positive response within 1 or 2 years after treatment but significant response to thinning msy be delayed several years. Annual diameter measurements taken in conjunction with an oak growth and yield study in the Boston Mountain area indicate that free-to-grow red and white oak crop trees in 40- to 70-year-old stands on medium sites should average about 0.20 to 0.25 inch diameter growth per year. To attain these growth rates, thinnings should be initiated before stands become overstocked and crop trees suffer appreciable reductions in crown size. Fertilization with N and P can also increase diameter growth of red and white oak crop trees and the increased growth rate will persist about 5 years. Red oaks will respond to larger applications of N than white oak and their response may continue beyond 7 years when fertilization and thinning treatments are combined.

Although differences in diameter growth between fertilized and nonfertilized treatments were statistically significant it is doubtful that the 7-year cumulative increase in diameter (0.2 to 0.5 inch) would justify the cost of a single commercial fertilizer application in these intermediate-aged stands. In considering silvicultural investments on these sites regulation of stand density in younger stands should have first priority.

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A GROWTH AND YIELD MODEL FOR UNTHINNED SLASH PINE PLANTATIONS INFECTED WITH FUSIFORM RUST[1/]

Warren L. Nance, Ronald C. Froelich, Tommy R. Dell, and Eugene Shoulders[2/]

Abstract.--Yield predictions under different levels of fusiform rust are essential in the development of management strategies for diseased plantations. A modification of an existing yield system is presented which predicts the growth and yield of infected slash pine plantations southwide. The new model was used to evaluate some alternative management schemes designed to reduce the yield loss directly attributable to fusiform rust.

INTRODUCTION

Yield prediction systems are essential to forest managers because they allow them to evaluate the effect of various management practices on the growth and yield of forest stands. The forest manager arrives at management strategies by considering the cost of some management practice weighed against its potential benefits in terms of growth and yield.

Unfortunately, yield prediction systems have not been available for plantations of slash (*Pinus elliottii* Engelm. var. *elliottii*) or loblolly pine (*P. taeda* L.) infected with fusiform rust (*Cronartium quercuum* Berk Miyabe ex Shirai f. sp. *fusiforme*). The disease is widespread throughout the planting range of both species and represents a major management problem in certain areas of the South. There are several yield prediction systems available for plantations of both species, but they do not consider a rust level parameter.

Without a yield prediction system for infected plantations, the forest manager cannot develop rational and economic disease management strategies to minimize the impact of the disease. For example, how can he estimate the yield loss likely to result in his infected plantations if he takes no action against the disease? Can he justify the cost of some control measure when he cannot predict the yield benefit likely to result from its use?

To approach this problem we modified an existing growth and yield model to incorporate a rust level parameter as one of the controlling variables used by the model to generate predicted yields. A previous paper (Nance et al. 19811 detailed the effects of the disease on the growth and yield of 187 unthinned research plots of slash pine in Louisiana and Mississippi. In this paper, we extend that work by analysing a combined data set taken from installations ranging from western Louisiana to South Carolina. The objectives are: (1) modify an existing growth and yield prediction system for unthinned slash pine to provide forecasts under alternate levels of fusiform rust, (2) evaluate the new system by comparing predicted and witnessed yields for plots covering a wide range of circumstances, and (3) demonstrate how the model can be used to answer important management questions for infected slash pine plantations.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ Warren L. Nance is Principal Plant Geneticist, Ronald C. Froelich is Principal Plant Pathologist, Tommy R. Dell is Mathematical Statistician, and Eugene Shoulders is Principal Silviculturist. All are employed by the Southern Forest Experiment Station, Forest Service--USDA.

DATA BASE

The slash pine data base for the analysis consists of two sets. Set A involves 100 plots from Mississippi and 87 plots from Louisiana measured periodically for rust infection and growth for 20 years. Detailed descriptions of these data appear in Shoulders (1976), Shoulders and Walker (1979), and Nance et al, (1981). These data were analysed extensively in the latter reference.

Set B consists of 281 slash pine plots from Alabama, Georgia, Florida and South Carolina. These data are part of a comprehensive growth and yield study installed by Union Camp Corporation beginning in 1973. These 281 plots were periodically measured for rust infection and growth for 17 years.

The site indexes (base age 25, estimated from an equation presented by Farrar, 1973) ranged from 25 to 80 feet with a mean of 62 feet in set A and 25 to 78 feet with a mean of 54 feet in set B. Planting density (number of trees planted per acre) was 1,210 for all plots In set A and ranged from 100 to 1,100 for set B. Establishment density (number of living trees per acre at age 5) ranged from 600 to 1,210 for set A with a mean of 996, and in set B ranged from 80 to 1,000 with a mean of 406. There were either 64 (Mississippi) or 49 (Louisiana) measured trees per plot in set A and 25 measured trees per plot in set B.

The percentage of living trees with a fusiform rust stem canker at age 5 ranged from 0 to 32 in set A with a mean of 4, and in set B ranged from 0 to 76 with a mean of 18. The cumulative percentage of established trees that had died with a stem canker by age 20 in set A ranged from 0 to 44 with a mean of 14, and in set B ranged from 0 to 78 with a mean of 21 by age 17.

MODELINGBACKGROUND

The plantation yield system we modified is described in its original form in Dell et al (1979) and was implemented in a computer program called USLYCOWG (Unthinned Slash and oblolly Yields for Cutover sites in the Western Gulf). Although the original model covered both slash and loblolly, this report covers only the modifications required for Incorporating fusiform rust into the slash pine model. Data used to construct the USLYCOWG model did not Involve significant levels of rust.

The USLYCOWG model.--The USLYCOWG prediction system can be briefly described in functional form as follows. For-an unthinned slash pine plantation, it is assumed that the current yield (Y) can be predicted using only three parameters: the age of the plantation in years (AP), the number of living trees per acre at that age (TL), and the mean height of the dominant and codominant trees in the plantation at that age (H_D). In functional form this appears as:

$$\hat{Y} = f(H_D, T_L, A_P) \qquad (1)$$

This form is not concerned with forecasting yields, since both HD and TL must be known at the age of interest, Ap. However, if predicted values for H_D and TL at age AP are substituted in place of known values, the model can be used to forecast yields.

In the case of HD, predicted values can be generated if one has an estimate of the site index (SI) of the planting site. The predicted mean dominant and codominant height is simply a function of two parameters:

$$H_D = f(S_I, A_P) \qquad (2)$$

In the case of survival, predicted values can be generated using a survival function that requires one to know site index (SI), the number of trees per acre initially planted on the site (TP), and the projection age (AP):

$$\hat{T}L = f(S_I, TP, AP) \qquad (3)$$

Hence, in the forecasting mode the USLYCOWG model simply replaces known values of H_D and TL with predicted values generated by the appropriate prediction equation, and the functional form for forecasting yield appears as:

$$Y = f(S_I, T_p, A_p) \qquad (4)$$

Modifications for fusiform rust.-Previous work by Nance et al.(1981) detailed some of the effects of fusiform rust associated mortality on the growth and development of plantations using set A. The primary effect was to lower the number of surviving trees from that expected without disease. The general form of the survival function we developed in that work was:

$$\hat{T}_L = f(T5, \hat{R}am, A_p) \qquad (5)$$

where: T_5 = number of surviving trees on the site at age 5
AP = age of the plantation in years
Ram = the cumulative proportion of trees that died with a stem canker by age AP

Note that TP of equation 3 was replaced with T_5 (the establishment density) and SI was eliminated because it contributed little to the prediction of T_L. Also note that this survival function is not useful in forecasting yields since Ram'must be known at age AP.

To make the survival function useful in forecasting yields, one must incorporate a predictor of Ram into the system that can be employed early in the life of the stand. This is specified in the following functional form:

$$\hat{Ram} = f(T_5, S_5, Ap) \quad (6)$$

where: S_5 = the proportion of trees living with a stem canker at age 5

Substituting predicted Ram for actual Ram in equation 5 yields the following survival model form which we fit in this paper:

$$\hat{T}_L = f(T5, S_5, Ap) \quad (7)$$

This function allows the forecasting of yields for infected plantations using the following functional form:

$$\hat{Y} = f(S_I, T_5, S_5, Ap) \quad (8)$$

The above strategy depends upon the assumption that current yield can be predicted by equation 1 regardless of rust history. This is verified in the next section.

MODELING RESULTS

In a previous work, it was found that current volumes at age 20 for all plots (regardless of rust history) in set A could be predicted accurately by the unmodified IJSLYCOWG system if observed HD and TL values at age 20 for each plot were input as arguments to equation 1 (Nance et al 1981). These results are shown in Table 1, along with the

Table 1.--Comparison of observed and predicted volumes and quadratic mean diameters for two data sets using known HD and TL values at age 17 or 20 as input to USLYCOWG.

DATA BASE	AGE	NO. PLOTS	VARIABLE PREDICTED	r 1/	BIAS 2/
	yrs.				%
SET A	20	187	VOLUME 3/	0.91	2.18
	20	187	QMDBH 4/	0.90	1.33
SET B	17	281	VOLUME	0.98	4.12
	17	281	QMDBH	0.91	4.45

1/ r denotes the simple correlation between observed and predicted values of the response variable.

2/ BIAS % = ((predicted - observed)/observed) x 100

3/ Volume = 0.0339 + 0.0026(d.b.h.^{2} x HEIGHT) for all trees (Moehring et al 1973).

4/ QMDBH = quadratic mean d.b.h., or the d.b.h. of the tree with average basal area.

corresponding results for set B. From these, it is clear that the fundamental component of the USLYCQWG system need not be modified for fusiform rust. Each of the data sets involves a wide range of rust histories, but volumes and diameters are predicted essentially as well as the data set used to validate the original model.

Now consider the case when survival must be predicted. We found in the present study that the following specific equations specify the concepts depicted by equations 5 and 7:

$$\hat{T}_L = [T_5^{-B_1[Ap-5]+1}] [(1-Ram)^{-B_2[Ap-5]}] \quad (9)$$

and

$$\hat{T}_L = [T_5^{-B_1[Ap-5]+1}] [(1-S_5)^{-B_2[Ap-5]}] \quad (10)$$

where B_1 and B2 in both equations are coefficients to be estimated.

The values of B_1 and B2 for both survival models for these data were estimated by linear regression after logarithmic transformation of the above equations, and they appear in Table 2. Both models generate predicted survivals that match well with the observed values for both data sets. As one would expect, the Ram model fits better than the 85 model.

We incorporated these new survival functions (equations 9 and 10 using the the overall coefficients) into USLYCOWG along with several programming modifications designed to make the program interactive and easy to use. The new program may be used free of charge via commercial telephone access to the Forest Service computer at Gulfport, Mississippi.

The modified USLYCOWG program was executed several thousand times in the process of generating stand tables for rust infected slash pine plantations, and the yields for a range of densities and S_5 rust levels for three diverse site indexes are given in Table 3.

APPLICATIONS

Table 3 gives a broad perspective of how various combinations of the four input variables (SI, T_5, S_5, and AP) interrelate to affect expected numbers of surviving trees and their cubic foot yields. Using values from this table, several concepts are exposed that need to be considered in arriving at disease management schemes for fueiform rust infected plantations of slash pine.

Pre-establishment management alternatives.--When considering the establishment of slash pine plantations in areas where fusiform rust infection

Table P.--Comparison of observed and predicted survival using Ram and S_5 for all measurement ages.

Model	Data Base	Observations 1/	B_1	B_2	r 2/	Bias 3/	Std. Error 4/
		No.				%	
Ram 5/	A	561	0.0017870	-0.0986730	0.79	0.01	110
	B	1124	0.0007555	-0.0922850	0.99	-1.40	26
	A+B	1685	0.0014976	-0.0884408	0.97	0.90	69
S_5 6/	A	561	0.0031113	-0.1038100	0.71	-0.10	125
	B	1124	0.0010951	-0.0841180	0.99	-2.60	38
	A+B	1685	0.0025306	-0.0712972	0.96	-0.50	84

1/ For set A, based on measurements at ages 10, 15, and 20 for 187 plots, and for set B based on ages 8, 11, 14, and 17 for 281 plots.

2/ r = simple correlation between observed and predicted number of surviving trees per acre.

3/ Bias = $\frac{\text{(predicted survival - observed survival)}}{\text{observed survival}} \times 100$

4/ Std. Error = standard deviation of (observed - predicted) survival in trees per acre (T/A) units.

5/ Ram = the cumulative proportion of trees living at age 5 that subsequently died with a stem canker.

6/ S_5 = the proportion of trees living at age 5 with a stem canker.

Table 3 .--A yield table from the modified USLYCOWG system showing the effects of site index, establishment density, and percent of fusiform rust stem infections at age 5 on predicted density and volume at ages 15 and 20.

Established Stand		Projected Plantation Age 15				20			
T_5 1/	S_5 2/	$\hat{T}_L$ 3/	Site Index 4/ 40	60	80	$\hat{T}_L$	Site Index 40	60	80
	%		---ft³/acre 5/----				---ft³/acre----		
400	0	344	329	1064	2165	319	570	1639	3119
	20	293	323	994	1986	251	516	1449	2715
	40	239	311	902	1758	185	462	1217	2210
	60	179	275	777	1436	120	375	908	1670
	80	109	232	585	1076	57	249	569	967
800	0	675	323	1380	3056	621	689	2252	4358
	20	576	328	1335	2866	489	651	2000	3870
	40	469	338	1232	2590	359	589	1732	3339
	60	351	334	1072	2178	233	498	1379	2586
	80	214	279	863	1645	111	358	884	1547
1200	0	1003	295	1462	3497	917	769	2605	5240
	20	855	310	1438	3339	722	715	2362	4682
	40	697	321	1392	3100	531	670	2090	3965
	60	522	335	1297	2740	344	584	1702	3264
	80	318	326	1029	2083	164	431	1102	2054

1/ T_5 = number of living trees at age 5.

2/ S_5 = proportion of living trees at age 5 with a stem canker.

3/ $\hat{T}_L$ = living trees per acre at the indicated age.

4/ base age 25 years.

5/ Cubic feet per acre volume of all trees greater than 4.5 in. d.b.h. to a 3 in. outside bark top, with a 0.5 ft. stump height (Dell et al. 1979).

is common, the manager can manipulate T_5 and/or S_5 in order to reduce the impact of fusiform rust on future yields. Increasing the number of planted trees per acre, or any other activity that would raise T_5, would tend to compensate for the additional mortality expected in the presence of rust. A second alternative would be to lower S_5 primarily through the use of genetically resistant planting stock, but perhaps also through oak eradication, pruning, or the application of fungicides. The dual approach of increasing T_5 and lowering S_5 at the same time is a third, and perhaps more desirable, alternative. Table 4 details some opportunities for increasing yields in plantations with site indexes of 60 and 80 for all three alternatives.

Table 4 shows that disease management strategies designed around the adjustment of T_5 alone would appear to be most viable in low to medium (less than 40 percent S_5) rust hazard areas. For example, for plantations with site index 80 where S_5 equals 80 percent, the potential yield gain through 20 years from raising T_5 from 400 to 800 trees per acre is only 580 cubic feet per acre. However, the potential yield gain from raising T_5 from 400 to 800 trees per acre with 40 percent S_5 on the same site is 1,129 cubic feet per acre. In high hazard areas, it may be impractical to establieh more trees per acre because most of them will become infected and eubsequently die.

Disease management strategies for high hazard areas must involve lowering S_5, either alone or in concert with increasing T_5. Whenever S_5 is lowered without increasing T_5, the potential for yield gain is higher on the more hazardous sites. For example, lowering S_5 from 40 to 0 where the site index is 80, with T_5 equal to 400 trees per acre, results in a yield gain of only 909 cubic feet per acre compared to a potential gain of 1,243 cubic feet per acre when S_5 is lowered from 80 to 40 percent on the same site with the same T_5. This differential effect is brought about by the fact that the relative contribution of an individual tree to stand yield increases as density decreases.

The combined strategy of increasing T_5 and lowering S_5 offers the highest possible yield gain, especially on the better sites. For example, in plantations with site index of 40, with T_5 equal to 400 trees per acre and S_5 equal to 80 percent, expected yield per acre at age 20 is 249 cubic feet per acre. Increasing T_5 to 1,200 and lowering S_5 to zero results in an expected yield of 769 cubic feet per acre --a gain of only 520 cubic feet per acre. This is in sharp contrast to the potential gains of 2,036 (2,605-569) and 4,273 (5,240-967) cubic feet per acre for the same adjustments to T_5 and S_5 in plantations with site indexes of 60 and 80 respectively. In terms of absolute gains, site index has an overwhelming effect on potential gain, Expressed in terms of percentage gains, the three examples above result in 209, 358, and 442 percent gains where site indexes are 40, 60, and 80, respectively. These comparisons demonstrate that the greatest gains can be made by concentrating control efforts on the better sites in the highest rust hazard areas. This may be particularly important in cases where resistant planting stock is in short supply.

Post-establishment management alternatives--Once a plantation is established and the realized T_5 and S_5 values are known, they can be used, along-with the estimated site index of the planting site, to forecast yields. Depending on the managers objectives, the projected stand may or may not meet some minimum expectation. If not, the manager may elect to replant the site, possibly with a different choice of planting stock and/or number of planted trees per acre. If the projected stand meets the minimum expectation, the manager may elect to continue managing the stand to some critical age at which other management decisions are made--such as whether or not to clearcut or thin the stand.

Consider the following example. A manager desires to have 344 surviving trees per acre by age 15. Via the prediction system this requires a minimum of 400 trees per acre be established on the site by age 5 (i.e., $T_5 = 400$) in a stand with $S_5 = 0$ (Table 3). If a plantation has less than 400 trees per acre at age 5, then that plantation will be replanted. The rule is simple enough when there is no rust infection, but becomes more complicated in the face of different levels of rust.

In fact, with S_5 values of 20, 40, 60, and 80 per cent, minimum establishment densities (T_5 values) of 471, 582, 783, and 1,299 would be required to achieve a target density of 344 trees per acre at age 15 (by equation 10 and coefficients listed in Table 2). The manager's decision to replant a given plantation due to inadequate establishment density would be strongly affected by the level of rust infection.

Moreover, the manager may want to adjust his minimum target density in the face of different levels of S_5, because stands that arrive at a set survival density at age 15 will differ markedly in their future survival rates to age 20, depending upon their rust history. This intrinsic liability may require the manager to perform a thinning of rust infected trees or else incur future losses. This potential disease loss may alter the manager's decision to continue the stand to the next decision period. For example, instead of the set target density at age 15, the manager may demand target densities for infected stands high enough so that the residual stand after thinning has the same density as a non-infected stand in which a thinning of rust infected trees is not needed.

The level of thinning at age 15 that may be required in a plantation to harvest anticipated rust related mortality may be estimated by applying equation 10 to generate the expected future mortality for stands that reach a given target density with various levels of rust. For example,

Table 4.--Opportunities for increasing cubic foot volume yields through age 20 by increasing T5, lowering S5, or both.

Base Stand			Expected Volume Increase By Adjusting T_5 and/or S_5 to:							
			T_5 = 800	1200	NC	NC	800	800	1200	1200
T_5	S_5	Volume	S_5 = NC1/	NC	40	0	40	0	40	0
Site Index 60										
No.	%		----------	----------	----------	ft^3/acre	----------	----------	----------	----------
	0	1639	613	966	2/					
400	40	1217	515	873		422		1035		1388
	80	569	315	533	648	1070	1163	1683	1521	2036
	0	2252		353						
800	40	1732		358		520				873
	80	884		218	848	1368			1206	1721
	0	2605								
1200	40	2090				515				
	80	1102			988	1503				
Site Index 80										
	0	3119	1239	2121						
400	40	2210	1129	1755		909		2148		3030
	80	967	580	1087	1243	2152	2372	3391	2998	4273
	0	4358		882						
800	40	3339		626		1019				1901
	80	1547		507	1792	2811			2418	3693
	0	5240								
1200	40	3965				1275				
	80	2054			1911	3186				

1/ NC = no change with respect to base stand
2/ blanks entries imply combinations that do not result in increases.

with T_5 = 400, S_5 = 0, and AP = 15, equation 10 predicts 344 trees per acre surviving at age 15. Changing AP to 20 predicts 319 trees surviving at age 20 --a mortality rate of 25 trees per acre (7 percent) between age 15 and 20. If one demands that all stands, regardless of their rust history, arrive at age 20 with the same density as the non-infected stand (319), then different minimum T_5 values would be required for different levels of rust, as detailed in Table 5.

Table 5.--Minimum establishment densities (T_5) required to reach the same target density at age 20 in stands with different levels of rust (S_5).

Minimum T_5 Required	With S_5 of	expected survival age 15	expected survival age 20	expected mortality 15-20
trees/acre	%	trees/acre		%
				1/
400	0	344	319	7
513	20	374	319	15
706	40	415	319	23
1109	60	483	319	34
2397	80	625	319	49

1/ column = $\frac{(\text{column 3} - \text{column 4})}{\text{column 3}} \times 100$

Table 5 shows that the expected mortality rates in the 15 to 20 year period are directly related to the rust history of each stand, and unless the manager thins the infected stands at age 15, the volume on those trees that die between age 15 and 20 would be lost. Hence, a thinning of rust infected trees at the indicated rates might be advisable. Unfortunately, the prediction system is not refined enough to predict which individual trees should be thinned --only the general level of thinning that is required. Hopefully, those infected trees with a low probability of survival to age 20 could be determined with some degree of confidence by inspection of the stand at age 15.

SUMMARY

Fusiform rust was incorporated into an existing growth and yield model for unthinned slash pine plantations (USLYCOWG) by modifying the survival function to incorporate percentage of living trees with a stem infection at age 5 as a rust level parameter. The new model provides opportunities for assessing the combined effects of site quality, stand density, level of fusiform rust infection, and age on future yields of infected, unthinned slash pine plantations. The model can be used to assess various management alternatives designed to reduce the impact of fusiform rust on future yields. The new model is now available in the form of an easy to use computer program operating on Forest Service computers accessible via commercial telephone lines.

Our research in the future will focus on corresponding model developments for loblolly pine plantations. Early indications are that survival in loblolly is less affected by fusiform rust than slash pine. Further refinements and extensions that consider thinning, degrade, and yield projections to longer rotations are also being considered.

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CROWN SIZE AND STAND DENSITY DETERMINE

PERIODIC GROWTH IN LOBLOLLY PINE PLANTATIONS[1]

James D. Burton and Eugene Shoulders[2]

Abstract.--An old-field loblolly pine (*Pinus taeda* L.) plantation was thinned and pruned at ages 11 and 14 to several different basal areas and crown ratios (crown ratio = 100 crown length/tree total height). Periodic growth at age 15-18, in d.b.h., basal area, and total stemwood volume were predicted by 2-variable regression equations involving expressions of crown size and stand density. Slant height of crown as a right circular cone was the best crown-size variable, and basal area was the best stand-density measure for predicting growth in volume and basal area. Number of trees and an index of crown surface as a cone were the best variables predicting d.b.h. growth. Use of crown surface index or slant height required measurement of both crown length and crown width. Crown ratio was nearly as effective as slant height in predicting volume and basal area growth and, if measurements are made from the ground, is obtained more accurately and cheaply. If crown size is to be measured by remote sensing, crown width may be the most accurate and cheapest measurement. Two-variable equations with (crown width)^2 and basal area predicted growth very effectively. Choice of crown-size variable depends on mensurational technique.

INTRODUCTION

Periodic growth in basal area, total stemwood volume, and quadratic mean d.b.h. in even-aged loblolly pine stands during the linear growth period depends on stand density and site quality, if all other factors remain the same. In thinned stands of uniform soil and site quality, and given different levels of green pruning, periodic growth can be expected to vary with stand density and mean crown size. Stand density is commonly expressed in terms of basal area or number of stems, or both. Crown size may be expressed in terms of length, width, length or width as a fraction of tree height, or their products. In this paper, we report the effects of selected stand-density and crown-size measurements on periodic growth in a loblolly pine plantation from age 15 to 18 years.

METHODS

The study was conducted in an old-field loblolly pine plantation near Monticello, Arkansas.[3] When the stand reached 11 years of age, 36 square 0.4-acre plots were laid out. Four levels of thinning and three levels of pruning were applied in all possible combinations and replicated three times; details are reported elsewhere (Burton 1981a). After three years the plots were thinned and pruned again to basal areas of 90, 70, 50, or 30 ft^2/acre and to crown ratios of 50, 39, or 25 percent. (Live crown ratios of 55, 40, and 25 percent were intended, but internode length and mortality of lower branches precluded their attainment.)

A salvage cutting 1 year later to remove glaze-damaged trees left residual basal areas on individual plots of 20 to 92 ft^2/acre. Crown ratios ranged from 23 to 53 percent. Heights of dominant and codominant trees averaged 46 feet.

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[3] Land and technical assistance were provided by Crossett Division, Georgia-Pacific Corporation.

Inventories were made after the salvage at age 15 and at age 18 of a 0.l-acre square plot at the center of each 0.4-acre treatment plot. Stem diameter at 4.5 feet (D) was measured on every tree. Up to 12 sample trees per plot were selected for additional bole and crown measurements. They were distributed proportionately among diameter classes. On plots containing 12 or fewer trees, all were measured as sample trees (some plots contained as few as 4 trees after the age 15 cut). Upper stem diameter, height, and crown length (CL) were measured with a tripod-mounted, magnifying, optical dendrometer. Crown width (CW) was measured in two directions at right angles using a metallic tape and the optical plumb described by Shepperd (1973). Bole volume and basal area of each sample were obtained by the height accumulation method (Lohrey and Dell 1969). The summary program computed stand volume/acre for each plot as the product of (mean volume/basal area ratio of sample trees) and (plot basal area/acre).

Because basal areas on individual plots were influenced by the amount of glaze damage (Burton 1981b), multiple regression analyses were used to determine the effects of stand density and crown parameters on volume, basal area, and diameter growth for the age 15-18 period. Dependent variables were:

AV = growth in total stemwood volume, inside bark, to the base of the apical bud, ft^3/acre

ABA = growth in basal area, ft^2/acre

AD = growth in quadratic mean d.b.h., inches

Primary independent variables included:

1. Basal area (BA) at beginning of period, ft^2/acre
2. Trees/acre (T) at beginning of period, number
3. Slant height (SH) of crowns of sample trees $= \sqrt{(CL)^2 + (0.5\ CW)^2}$, feet
4. CW x SH = an index of crown surface (CS) area as a right circular cone, $feet^2$
5. $(CW)^2$ = an index of crown projection area, $feet^2$
6. $(CW)^2$ x SH = an index of crown volume (CV), $feet^3$
7. Crown ratio (CR) = (100 CL)/(total height), percent

Equations with 1, 2, or 3 independent variables were computed, together with their coefficients of determination (R^2), standard errors of estimate (SE est), and relative mean squared residuals (RMSQR), Grosenbaugh's (1967) procedure was used with some constraints. Not all possible combinations of independent variables were of concern. In 2-variable regressions, one variable was a stand-density expression, either BA or T, and the second independent variable was a crown-size expression, either SH, CS $(CW)^2$, CV, or CR. In 3-variable regressions, the third independent variable was the product of the first and second independent variables. Regressions selected as best, on the basis of minimum RMSQR were generated only by the foregoing combinatorial rules and were required to be biologically plausible.

RESULTS AND DISCUSSION

In single-variable regressions, basal area was the best independent variable predicting volume growth and basal area growth; number of trees was next (Table 1). Crown width squared was the best predictor of d.b.h. growth; crown volume index and crown surface index did almost as well; all the crown-size variables were much more effective than either of the stand-density variables. Standard errors ranged from 80 to 190 ft^3/acre of volume, 3 to 6 ft^2/acre of basal area, and .21 to .36 inch of d.b.h.

Table 1.--Goodness of fit statistics for single-variable equations predicting period growth in stand volume, basal area, and quadratic mean d.b.h.

Y	X	R^2	SE est [1/]	RMSQR
AV	BA	0.8279	80.35	.1771
	T	.7192	102.63	.2890
	SH	.2023	172.99	.8212
	CS	.0944	184.32	.9322
	$(CW)^2$	.0361	190.16	.9923
	CV	.0375	190.02	.9908
	CR	.3646	154.39	.6541
ABA	BA	.7838	2.90	.2226
	T	.6237	3.83	.3873
	SH	.3409	5.06	.6785
	CS	.2063	5.56	.8171
	$(CW)^2$	.1147	5.87	.9111
	CV	.1172	5.86	.9088
	CR	.5273	4.29	.4866
AD	BA	.1201	.36	.9058
	T	.2457	.33	.7765
	SH	.5527	.26	.4605
	CS	.6741	.22	.3355
	$(CW)^2$	.7096	.21	.2990
	CV	.6878	.22	.3214
	CR	.2666	.33	.7550

[1/] $\sqrt{\text{residual mean square}}$

The best 2-variable equation predicting volume growth involved basal area and crown slant height; its RMSQR was only .1201 (Table 2). Number of trees was nearly as good as basal area in multiple regressions. All the 2-variable equations tested accounted for at least 83 percent of the variation in periodic volume growth. The standard errors and the RMSQRs of the 3-variable regressions were not much smaller than those of the corresponding 2-variable equations; in some instances they were larger. Interaction contributed little to the prediction effectiveness,

The best 2-variable equation predicting basal area growth involved basal area and slant height (Table 3); the second best involved basal area and crown surface index. No 2-variable regression had an RMSQR greater than .1661, a standard error greater than 2.51, or accounted for less than 84 percent of the variation in basal area growth. The 3-variable regressions were no real improvement over the 2-variable.

The best 2-variable equation predicting d.b.h. growth involved number of trees and crown surface index (Table 4); the second best involved basal area and crown surface index; they accounted for 87 and 86 percent of the variation, respectively.

Table 2.--Goodness of fit statistics for P-variable and 3-variable equations predicting periodic volume growth

Independent variables1/	2-variable equations			3-variable equations		
	R^2	SE est2/	RMSQR	R^2	SE est2/	RMSQR
BA and SH	.8867	66.17	.1201	.8885	66.67	.1220
CS	.8769	68.98	.1306	.8850	67.70	.1258
$(CW)^2$	.8652	72.19	.1430	.8749	70.60	.1368
CV	.8660	71.97	.1421	.8813	68.77	.1298
CR	.8712	70.56	.1366	.8728	71.21	.1391
T and SH	.8752	69.46	.1324	.8793	69.37	.1320
CS	.8548	74.91	.1540	.8786	69.56	.1328
$(CW)^2$	.8339	80.13	.1762	.8679	72.56	.1445
CV	.8264	81.92	.1841	.8735	71.00	.1383
CR	.8288	81.35	.1816	.8312	82.03	.1846

1/In 3-variable regressions the 3d variable was the product of the stand-density and the crown-size variables, i.e., an interaction term.

2/ $\sqrt{\text{residual mean square}}$

Table 3.--Goodness of fit statistics for 2-variable and 3-variable equations predicting periodic basal area growth

Independent variables1/	2-variable equations			3-variable equations		
	R^2	SE est2/	RMSQR	R^2	SE est2/	RMSQR
BA and SH	.9331	1.64	.0709	.9332	1.66	.0730
CS	.9215	1.77	.0922	.9287	1.72	.0780
$(CW)^2$	.9005	2.00	.1055	.9125	1.90	.0957
CV	.9019	1.98	.1041	.9207	1.81	.0867
CR	.9124	1.87	.0929	.9177	1.84	.0900
T and SH	.9080	1.90	.0976	.9088	1.94	.0998
CS	.8852	2.15	.1218	.9068	1.96	.1020
$(CW)^2$	.8537	2.42	.1152	.8913	2.12	.1189
CV	.8433	2.51	.1661	.8970	2.06	.1126
CR	.8569	2.40	.1518	.8634	2.38	.1494

1/In f-variable regressions the 3d variable was the product of the stand-density and the crown-size variables, i.e., an interaction term

2/ $\sqrt{\text{residual mean square}}$

Table 4.--Goodness of fit statistics for 2-variable and 3-variable equations predicting periodic growth in quadratic mean d.b.h.

Independent variable[1]	2-variable equations			3-variable equations		
	R^2	SE est[2]	RMSQR	R2	SE est[2]	RMSQR
BA and SH	.8405	.1561	.1691	.8735	.1412	.1384
CS	.8565	.1481	.1522	.8618	.1474	.1511
$(CW)^2$	.8277	.1622	.1827	.8280	.1646	.1881
CV	.8071	.1717	.2046	.8079	.1740	.2101
CR	.7002	.2140	.3180	.7591	.1948	.2635
T and SH	.8502	.1512	.1586	.8769	.1392	.1346
CS	.8665	.1428	.1416	.8715	.1423	.1405
$(CW)^2$	.8378	.1574	.1720	.8388	.1594	.1764
CV	.8271	.1624	.1834	.8280	.1646	.1881
CR	.7828	.1822	.2304	.8109	.1726	.2068

1/In 3-variable regressions the 3d variable was the product of the stand-density and the crown-size variables. i.e.. an interaction term.

2/ $\sqrt{\text{residual mean square}}$

Crown surface index was the second best crown-size variable to include with basal area in 2-variable regressions for predicting volume growth and basal area growth. However, slant height is a prerequisite to calculating crown surface (as we did in this study), and unless crown surface or crown volume offers a markedly smaller RMSQR than slant height, there is no advantage in the computation.

If crown size is to be measured by remote sensing, crown width may be the cheapest and most accurate crown-size measurement. Iwo-variable equations with $(CW)^2$ and basal area resulted in small RMSQRs in this study and accounted for 83 to 90 percent of the variation in periodic volume, basal area, and diameter growth. Equations for predicting growth from these parameters are:

$$AV = 15.48 + .341(CW)^2 + 9.17\ BA$$

$$ABA = -.922 + .0194(CW)^2 + .287\ BA$$

$$AD = 1.187 + .00295(CW)^2 - .00688\ BA$$

NOTE: Goodness of fit statistics are given in tables 2 through 4.

When tree measurements are to be made by people on the ground with existing technology, crown length can be measured more accurately and more cheaply than crown width. Depending on the mensurational technique available, some measurements can be better bargains than others, and this will affect the choice of regressions. In this study, both slant height and crown surface index, in regressions with basal area, resulted in only slightly smaller RMSQRs than did crown ratio; CR was obtained more cheaply.

The best 2-variable equation involving crown ratio and predicting total stemwood volume growth was:

$$AV = -29.04 + 4.56\ CR + 8.07\ BA$$

Solving this equation for crown ratios of 25, 37.5, and 50 percent, for basal areas of 25 through 90 ft^2/acre, and converting periodic to annual growth, we obtain the values in table 5. Consider a thinned and pruned loblolly pine plantation with a mean CR = 37.5 percent and a BA = 50 ft^2/acre, on a site similar to this one: The periodic annual volume growth from age 15 to 18 should be 182 ft^3/acre.

Table 5.--Predicted periodic annual growth, age 15-18, in total stemwood inside bark in thinned and pruned loblolly pine plantations, given various basal areas and crown ratios

Beginning basal area	Crown ratio 25	37.5	50
	Ft^3/acre		
25	96	115	134
30	109	128	147
40	136	155	174
50	163	182	201
60	190	209	228
70	217	236	255
75	230	249	268
80	244	263	282
90	270	289	308

The best 2-variable equation involving crown ratio and predicting basal area growth was:

$$ABA = 3.28 + .253\ CR + .227\ BA$$

Solving this equation for the same crown ratios and basal areas, Table 6 is obtained. Our hypothetical plantation should have a periodic annual BA growth = 5.8 ft^2/acre.

The 2-variable equation for d.b.h. growth involving basal area and crown ratio was:

$$AD = .970 + .033\ CR - .015\ BA$$

Solving this equiation for the same crown ratios and basal areas, Table 7 is obtained.

Table 6.--Predicted periodic annual growth, age 15-18, in basal area in thinned and pruned loblolly pine plantations, given various basal areas and crown ratios

Beginning basal area	Crown ratio 25	37.5	50
-Ft^2/acre-	-Ft^2/acre-		
25	2.9	4.0	5.0
30	3.3	4.3	5.4
40	4.0	5.1	6.1
50	4.8	5.8	6.9
60	5.6	6.6	7.7
70	6.3	7.4	8.4
75	6.7	7.7	8.8
80	7.1	8.1	9.2
90	7.8	8.9	9.9

Table 7.--Predicted periodic annual growth, age 15-18, in quadratic mean d.b.h. in thinned and pruned loblolly pine plantations, given various basal areas and crown ratios

Beginning basal area	Crown ratio 25	37.5	50
-Ft^2/acre-	-Inches-		
25	0.47	0.61	0.75
30	.45	.59	.72
40	.40	.54	.67
50	.35	.49	.62
60	.30	.44	.57
70	.25	.39	.52
75	.18	.36	.50
80	.20	.34	.47
90	.15	.29	.42

For comparable stand densities and crown ratios, both volume and basal area growth were less at 15 to 18 years than at 11 to 14 years (Burton 1981a). This trend reflects the normal decline in growth rate with age and suggests that periodic annual increment had culminated on this site before age 18.

The effects of density and crown parameters on basal area and volume growth were more pronounced at ages 15 to 18 than at ages 11 to 14. Differences in basal areas retained on the plots at ages 11 and 15 and in post-pruning live crown ratios at the two ages undoubtedly contributed to these changes. The heaviest thinning at age 11 left a residual basal area of 40 ft^2/acre, whereas the salvage cutting at age 15 reduced basal area on some plots to 20 ft^2/acre. Heaviest stocked plots contained 100 ft^2/acre of basal area after thinning at age 11 and 92 ft^2/acre after the salvage at age 15. Crown ratio at age 11 ranged from 37 to 52 percent of total height and at age 15 from 23 to 53 percent.

SUMMARY AND CONCLUSIONS

These results reconfirm the fact that both stand density and crown size affect growth of young loblolly pine plantations. Moreover, they indicate no significant interaction between density and crown size in their effects on tree and stand growth.

Two-variable regressions containing residual basal area and crown ratio as independent variables were satisfactory for predicting periodic diameter, basal area, and volume growth of a young loblolly pine plantation in south Arkansas that was thinned to basal areas of 20 to 92 ft^2/acre and pruned to create crown ratios of 23 to 53 percent.

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GROWTH AND DEVELOPMENT OF A PO-YEAR-OLD UNTHINNED SPRUCE PINE PLANTATION[1/]

John R. Toliver and James E. Hotvedt[2/]

Abstract ,--Spruce pine seedlings were planted on an old-field site in southeastern Louisiana. At age 20 years, survival was 67%, number of trees per acre was 1170, the average diameter of the trees was 5.05 inches, and the average height was 43 feet. In comparison, naturally seeded loblolly pine trees in the stand and of the same age had an average diameter of 6.92 inches and an average height of 48 feet.

INTRODUCTION

Although spruce pine (*Pinus glabra* Walt.) grows throughout the Coastal Plain from South Carolina to Florida and Louisiana (Dorman 1976), it is found mainly in southern Alabama and Mississippi, and southeastern Louisiana (Sternitzke and Nelson 1970). Spruce pine usually occurs as a single tree or as a small group of trees in association with loblolly pine (*P. taeda* L.) and hardwoods in the second bottoms and the moist fringes surrounding longleaf pine (*P. palustris* Mill.)(Walker 1980). These sites often consist of sandy loam soils intermediate between dry sandy soils and alluvial bottomland soils (Koch 1972).

Spruce pine is the most tolerant southern pine species, but only moderately intolerant by hardwood standards (Putnam et al. 1960). It is the most effective of the southern pine species in competing with ground cover and hardwood reproduction.

Growth rates of spruce pine are considered good to excellent (Putnam et al. 1960). Mature trees may grow to diameters of 2 or 3 feet and to heights of 100 feet or more (Koch 1972). Although large trees of spruce pine can have good form and clear boles, young trees are often crooked and limby. These characteristics probably result from the shade tolerance of the species. It is rarely found in pure stands large enough to warrant commercial management and harvesting of the species by itself, and it has been planted very little commercially, to our knowledge, except for Christmas tree production. Harvested trees are usually mixed with other species of southern pines and hardwoods for pulp and paper products. Indeed, pulping characteristics and yields obtained are very similar to those of the more common southern pines (Koch et al. 1958). Specific gravity of the wood is usually lower, however, averaging 0.43 (Koch 1972). Spruce pine may be harvested for sawtimber to a limited extent, although it is not a preferred species for veneer.

Spruce pine has been planted on a small scale in South Carolina (Dorman 1976) and a few scattered plantations possibly exist throughout the South. Nevertheless, very little information exists on the growth and development of the species. The purpose of this paper is to discuss the growth and development of a 20-year-old unthinned plantation of spruce pine located in southeastern Louisiana.

METHODS

Description of the Plantation

The spruce pine plantation is located on a coastal plain site in East Feliciana Parish, near Clinton, Louisiana. Underlying soils include two major types: Lexington silt loam, a well drained moderately permeable soil and Providence silt loam, a moderately well drained slowly permeable soil. Average annual rainfall for the 'area is 62 inches.

The spruce pine trees were planted on an old-field site, approximately 2 acres in size, in early spring of 1958. According to A.B. Crow (personal communication), the field was burned and 1-O bareroot seedlings were planted on a 5x5 foot spacing. The plantation was initially

1/Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia November 4-5, 1982.

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established for Christmas tree production. However, no cultural work, thinnings, or harvests were done after the trees were planted and the trees were essentially left to grow as an unmanaged old-field plantation. In the fall of 1977, and before the stand was to be thinned, the opportunity existed to measure the closely spaced spruce pine trees' at age 20 and to analyze their growth and development. Also growing within the stand were 221 loblolly pine trees of approximately the same age (based on increment cores). It is assumed their origin was from windblown seed which germinated shortly after the plantation was established.

Measurements

Survival was determined by first choosing a random sample of 15 rows of trees. Then, in each row the number of live spruce pine trees present out of 20 spots that should have been planted was determined and the percent survival calculated.

The diameter (4.5 feet above ground) of all live standing trees was measured to the nearest tenth of an inch with a standard diameter tape. The total height of every tenth tree was measured to the nearest foot with a Suunto clinometer. Additional measurements taken on every twentieth tree included: (a) height in feet to the first live limb, (b) age based on a count of growth rings in an increment core, (c) increment measurement of the last 5 growth rings, and (d) increment measurement of the last 10 growth rings. Similar measurements were taken on the loblolly pine trees for use in comparing the growth of the two species.

All border trees were eliminated from the data sets for statistical purposes.

RESULTS AND DISCUSSION

Survival of the spruce pine trees in the 20-year-old plantation was 67 percent, or approximately 1170 live spruce pine stems per acre. In addition, there were another 110 loblolly pine stems per acre scattered throughout the stand.

The average diameter (dbh) at age 20 of the spruce pine trees was 5.05 inches (ranging from 1.50 to 12.30 inches). Two-thirds of the trees were less than 6 inches in diameter (Figure 1.). While this still left over 400 trees/acre that were 6 inches dbh or greater, only six percent of the total number of trees were greater than 8 inches in diameter. Assuming 67% survival, the basal area was calculated to be 178 square feet/acre.

In comparison, the average diameter of the loblolly pine trees was 6.92 inches (ranging from 2.90 to 14.40 inches). Thirty-six percent of these trees were greater than 8 inches in diameter and only 30 percent were less than 6 inches.

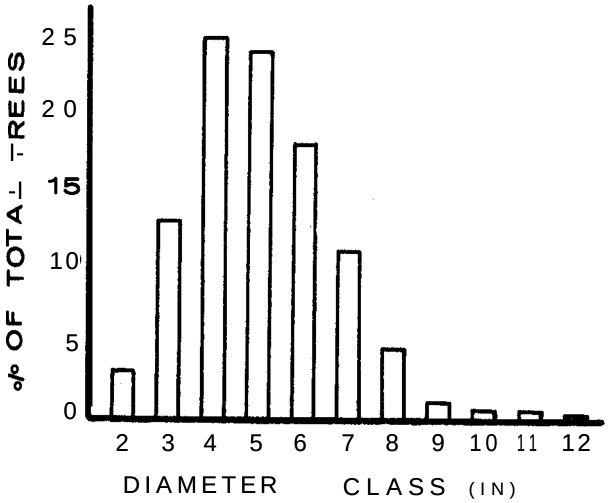

Figure 1. Diameter distribution of 20-year-old plantation-grown spruce pine trees (5x5 ft. spacing)

Average diameter growth of the spruce pine trees over the first 10 years was 4.03 inches, or 0.40 inches per year (calculated from Table 1.) Average diameter growth from ages 10 to 15 years was 0.67, or 0.13 inches per year--an annual growth rate of 32 percent that of the annual growth rate during the first 10 years. During the last 5 years (ages 15-20 years) the growth declined further to an annual rate of 0.07 inches per year or only 18 percent of the annual growth rate during the first 10 years. It is apparent that the stand should have been thinned at age 10, and definitely by age 15 years, if sawtimber was the intended product.

The average annual diameter growth for the last 10 years was greater for the trees in diameter classes above 6 inches. However, the mean percentage growth rates for the last ten years by diameter class were about equal, ranging from 19-25%. It is assumed that thinning would have increased the growth rates of the remaining trees.

The mean height of those spruce pine trees measured for height was 43 feet (ranging from 23 to 53 feet). The majority (60%) of these trees, however, ranged in height from 42 to 52 feet tall (Figure 2). It appears that some spruce pine trees will exert dominance and maintain relatively good growth, as the taller trees were also in the larger diameter classes. This site (loblolly pine SI 90) is not an exceptional site for spruce pine growth. In natural stands in Louisiana it grows better on more moist sites where loblolly pine site index may be 110 or greater.

The loblolly pine trees averaged 48 feet in height (ranging from 32 to 59 feet). Site index based on the taller loblolly trees was calculated to be 90 (50-year site index curve).

Table 1. Stand data by diameter classes for 20-year-old plantation-grown spruce pine trees (5x5 foot spacing, 2.0 acres).

Diameter Class (in.)	No. Trees	GR5[1] (in.)	GR10[2] (in.)	Ht. (ft.)	DLL[3] (ft.)
2	61	.18(4)[4]	.62(4)	34(7)	29(4)
3	268	.22(15)	.77(15)	34(23)	31(13)
4	503	.28(31)	.88(31)	41(47)	32(29)
5	482	.34(24)	.98(24)	44(44)	33(18)
6	354	.43(21)	1.17(21)	45(36)	31(15)
7	222	.49(16)	1.34(16)	47(24)	32(15)
8	88	.70(5)	1.68(5)	47(10)	28(3)
9	22	1.00(1)	2.00(1)	47(1)	
10	5	.80(1)	2.00(1)	52(1)	35(1)
11	4	--	--	--	--
12	1				

[1] increment growth from age 15-20 years
[2] increment growth from age 10-20 years
[3] height to first live limb
[4] number of trees sampled

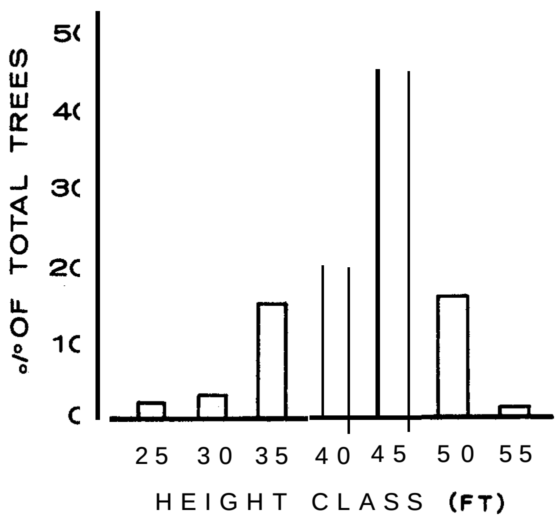

Figure 2. Height-distribution of 20-year-old plantation grown spruce pine trees (5x5 ft. spacing).

Natural pruning of the spruce pine trees was poor relative to the loblolly. Although height to the first live limb averaged 31 feet, many dead limbs persisted on the trees and very few trees had a clear 16-foot log. The high stem density should improve natural pruning so it is assumed that wider spacing than 5x5 feet would decrease stem quality. Poor natural pruning can be attributed to the shade tolerance of spruce pine. Although measurements related to stem form were not taken, many of the smaller trees were crooked and of poor quality. We would estimate that 10-15 percent of the trees were straight and of good form, particularly in the larger diameter classes.

CONCLUSIONS

Spruce pine can be successfully established by planting seedlings on pine sites in the South. Spacing as close as 5x5 feet may be too dense, resulting in considerable decreases in growth after the first 10 years. Height growth did not appear to be affected by spacing however. Although conventional spacings such as 6x8 or 8x8 feet would probably increase growth, the wider spacing could also contribute to poor natural pruning of spruce pine.

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COMPARING GROWTH AND YIELD BETWEEN 31-YEAR-OLD SLASH AND LOBLOLLY PINE PLANTATIONS[1]

Terry R. Clason and Quang V. Cao[2]

A growth comparison study between slash and loblolly pine was established at Homer, Louisiana in the winter of 1949. Treatment plantings included pure slash, pure loblolly, and alternating rows of slash and loblolly. At age 15 the pure slash and loblolly plantings were thinned to 300 TPA, while the mixed plantings were not thinned due to high slash pine mortality. Growth data has been collected on a periodic basis since 1956. In 1981, the study was harvested and felled tree data collected. After 31 years, slash and loblolly pine stand performance was comparable. Loblolly pine is the preferred species to plant in northwest Louisiana.

INTRODUCTION

Two species of pines have been planted in northwest Louisiana. Loblolly pine (*Pinus taeda* L.) is native to the region, while slash pine (*Pinus elliottii* Engelm.) is not. Slash pine's natural range does not extend west of the Mississippi River or more than 100 miles from the Gulf of Mexico. Planting slash pine in north Louisiana will subject it to environmental conditions different from those under which the species evolved. Thus, the susceptibility of slash pine to damage from disease and extreme climatic conditions as its range is extended northward is a major concern.

METHODS AND PROCEDURES

In 1950, a slash and loblolly pine growth comparison study was established at Homer, Louisiana. Both species were planted in pure stands and alternating row mixtures at a 6 x 8 spacing on 0.5-acre plots with each treatment replicated four times. Soil types were fine sandy loams of the Bowie, Luverne and Ruston series with a site index of 65 for loblolly pine at age 25.

After the 1964 growing season, stocking rate of all pure stands was reduced to 300 trees per acre (TPA). Stumps were sprinkled with Borateen for *Fomes annossus* control. Single-row mixtures were not thinned because slash pine mortality was very high. Except for periodic prescribed burns, no further silvicultural treatments were applied until the stands were harvested in January 1981.

Diameter and height were measured periodically from 1956 to 1980. Merchantable volume to a 3-inch top diameter was calculated using equations from Merrifield and Foil (1967).

Statistical analysis of the study was confounded in 1956 because high seedling mortality and intense brush competition necessitated the removal of two replications from the study. To provide a valid statistical test, three-0.1 acre measurement plots were established in each of the remaining 0.5 acre plots.

RESULTS

Stand Development Prior to Thinning

Mortality

Slash and loblolly mortality in pure and mixed stands had peaked by age 7 (Table 1). Seedling mortality varied considerably between

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Table 1. Pine stocking for pure and mixed stands of slash and loblolly pine from initial planting to stand age 15

	Planting	Stand age 7	10	13	15
	----------(Trees/Acre)----------				
Pure Stands					
Slash	908	616	611	601	504
Loblolly	908	755	750	738	655
Mixed Stands					
Slash	454	231	227	200	145
Loblolly	454	392	388	374	339

species with slash losses being greater. Slash mortality was 40.0 percent in pure stands and 49.1 percent in mixed stands, while loblolly had 16.8 and 13.6 percent. From age 7 to 13 mortality rate averaged 2.3 percent for both species in pure stands and 13.4 percent for slash and 4.6 percent for loblolly in mixed stands. Periodic mortality rate increased between ages 13 and 15. Subsequently, by age 15, slash and loblolly totaled 44.4 and 27.8 percent in pure stands and 66.1 and 25.3 percent in mixed stands.

Diameter Growth

Average diameters during the first 15 years of growth are presented in Table 2. Mean annual incremental diameter increases for ages 7, 10, 13 and 15 in pure slash and loblolly pine stands were similar. Mean annual increment (MAI) for both species peaked at age 10 when slash averaged 0.49 inches/year and loblolly 0.51 inches/year. During the next 5 years annual increment declined to 0.44 and 0.43 inches for slash and loblolly. In mixed stands, slash had a slower rate of increase averaging, at age 15, 0.34 inches/year, while loblolly had a faster rate, averaging 0.51 inches/year.

Height Growth

Slash and loblolly pine in pure stands averaged 45 and 46 feet in height at age 15 (Table 3). Average height growth for each species was the 29 feet from age 7 to 15. In mixed stands slash and loblolly height growth differed greatly. By age 15, slash pine averaged 41 feet in height and loblolly 47 feet. In addition, height growth between ages 7 and 15 averaged 27 and 30 feet for slash and loblolly, respectively.

Basal Area Growth

Pure stand basal area reached a maximum at age 15 for both slash and loblolly pine (Table 4). Mean annual basal area increments varied by species at ages 7, 10, 13, and 15. Although basal area growth of slash during the first 15 years was less than loblolly, the growth pattern of both species was similar. Maximum (MAI), 9.2 ft^2/acre for slash and 11.3 ft^2/acre for loblolly, was achieved by age 13. Mortality in both slash and loblolly stands between ages 13 and 15 resulted in a MAI at age 15 of 8.3 and 10.3 ft^2/acre for slash and loblolly, respectively. Basal area for slash pine in mixed stands totaled 22 ft^2/acre at age 15 compared to a loblolly total of 114 ft^2.

Merchantable Volume Growth

Volume growth results were similar to basal area (Table 5). By age 15, pure slash had accumulated 1815 ft^3/acre with a MAI of 121 ft^3/acre and loblolly 2235 ft^3/acre with a MAI of 149 ft^3. Both species reached a maximum MAI, 133 ft^3 for slash and 153 ft^3 for loblolly, by age 13. Subsequent mortality attributed to a decline in MAI at age 15. After 15 years, volume growth of slash pine in mixed stands was inferior to loblolly producing only 225 ft^3/acre with a MAI of 15 ft^3/acre. Loblolly yielded 1779 ft^3/acre with a MAI of 118.6 ft^3/acre.

Table 2. Average DBH for pure and mixed stands of slash and loblolly pine from stand age 7 to 15

	Stand age			
	7	10	13	15
	(Inches)			
Pure Stands				
Slash	3.3	4.9	5.7	6.6
Loblolly	3.3	5.1	5.9	6.4
Mixed Stands				
Slash	2.8	3.8	4.2	5.1
Loblolly	3.8	5.8	6.8	7.7

Table 3. Average height for pure and mixed stands of slash and loblolly pine from to stand age 7 to 15

	Stand age			
	7	10	13	15
	(Feet)			
Pure Stands				
Slash	16	27	37	45
Loblolly	17	30	39	46
Mixed Stands				
Slash	14	25	32	41
Loblolly	17	29	39	47

Table 4. Basal area for pure and mixed stands of slash and loblolly pine from to stand age 7 to 15

	Stand age			
	7	10	13	15
	(Feet^2/Acre)			
Pure Stands				
Slash	37	86	120	125
Loblolly	47	109	147	154
Mixed Stands				
Slash	10	20	26	22
Loblolly	32	75	106	114

Table 5. Merchantable volume for pure and mixed stands of slash and loblolly pine from stand age 7 to 15

	Stand age			
	7	10	13	15
	(Feet^3/Acre)			
Pure Stands				
Slash	280	872	1600	1815
Loblolly	360	1160	2000	2235
Mixed Stands				
Slash	80	200	328	225
Loblolly	232	800	1464	1779

Table 6. Stand data for pure stands of slash and loblolly pine thinned at age 15

	Trees per acre	DBH	Height	Basal area per Acre	Volume per Acre
		(Inches)	(Feet)	(Feet^2)	(Feet^3)
Before thinning					
Slash	504	6.6	45	125.0	1815
Loblolly	655	6.4	46	153.7	2235
Removed in thinning					
Slash	203	6.2	44	44.7	621
Loblolly	359	5.9	45	71.7	982
After thinning					
Slash	301	6.9	46	80.3	1193
Loblolly	296	7.1	48	82.0	1253

Stand Development After Thinning

Thinning

Prior to the 1964 thinning pure slash and loblolly stands contained 1815 and 2235 ft^3/acre of merchantable volume (Table 6). Wood volumes removed during the thinning averaged 621 ft^3/acre for slash and 982 ft^3/acre for loblolly. Average stand diameter following thinning increased from 6.6 to 6.9 inches for slash and 6.4 to 7.1 inches for loblolly, and residual stand volumes were 1193 and 1253 ft^3/acre. Since the mixed stands were not thinned in 1964, further growth comparisons were discontinued.

Mortality

At age 31 mortality rate in the thinned slash and loblolly stands was 33.6 and 23.9 percent (Table 7). Following the thinning periodic mortality rate until age 24 was approximately 5 percent for both species. Between ages 24 and 27 slash stand experienced a periodic mortality rate of 17 percent, while loblolly had only 4 percent. Subsequently, both species had a mortality rate of 16 percent for the 27 to 31 year growth period.

Table 7. Pine stocking for pure stands of slash and loblolly pines from thinning at stand age 15 to age 31

	Stand age				
	15	21	24	27	31
	Trees/Acre				
Slash	301	291	286	237	200
Loblolly	296	283	278	267	225

Table 8. Average DBH for pure stands of slash and loblolly pine from thinning at stand age 15 to age 31

	Stand age				
	15	21	24	27	31
	Inches				
Slash	6.9	8.0	8.8	9.4	9.9
Loblolly	7.1	8.1	8.7	9.3	9.8

Diameter Growth

Average diameter increase during the 16 years after thinning favored slash pine (Table 8). The mean annual incremental diameter increase for slash and loblolly pine was 0.186 and 0.169 inches. Through age 24 slash pine diameter increased at an annual rate of 0.211 inches, while loblolly increased by 0.177 inches. Although the slash stands, had 62 percent more mortality than loblolly between ages 24 and 31, annual diameter increase for both species was 0.157 inches.

Height Growth

From age 15 to 21 slash pine height growth averaged 2.83 ft/year which was 0.7 foot greater than loblolly (Table 9). An ice storm at age 24 reduced periodic annual growth between ages 21 and 24 to 1 foot for each species. In the succeeding three years (ages 24 to 27) slash and loblolly stands averaged 3 ft/year. Average height in the slash stand declined by 1 foot from age 27 to 31, while loblolly increased by 3 feet. By age 31, height in both stands averaged 74 feet.

Basal Area Growth

By age 31, basal area in the slash and loblolly stands had increased by 30.6 and 39.9 ft^2/acre, respectively (Table 10). Nine years after thinning, through age 24, slash pine basal area growth exceeded loblolly by 6 ft^2/acre, averaging 4.77 ft^2/acre annually. High slash mortality between ages 24 and 27 resulted in a 5 ft^2/acre basal area reduction. During the same period loblolly basal area increased by 11 ft^2/acre. From age 27 to 31, both species experienced an 8 ft^2/acre decline in basal area.

Merchantable Volume Growth

Since the 1964 thinning, slash and loblolly stands have produced 1896 and 2103 ft^3/acre of merchantable volume, respectively (Table 11). Slash pine exhibited an early, rapid response to thinning. From age 15 to 24, slash pine volume growth exceeded loblolly by 176 ft^3/acre. Slash MAI during this period surpassed loblolly by 19.6 ft^3. Slash pine mortality, between ages 24 and 27, reduced volume growth for the period to 60 percent of the previous 3 years. Concurrently, loblolly volume growth was 531 ft^3/acre, nearly doubling slash growth. Over the final 4 years, ages 27 to 31, slash stand growth was 33 percent less than loblolly.

Table 9. Average height for pure stands of slash and loblolly pine from thinning at stand age 15 to age 31

	Stand age				
	15	21	24	27	31
	Feet				
Slash	46	63	66[1]	75	74
Loblolly	48	61	63[1]	71	74

[1] Average height of trees suffering no crown damage. Average height of trees with broken tops was 51 and 52 feet for slash and loblolly pine, respectively.

Table 10. Basal area for pure stands of slash and loblolly pine from thinning at stand age 15 to age 31

	Stand age				
	15	21	24	27	31
	$Feet^2/Acre$				
Slash	80.3	104.8	123.2	118.3	110.9
Loblolly	82.0	102.6	118.9	129.8	121.2

Table 11. Merchantable volume for pure stands of slash and loblolly pine from thinning at stand age 15 to age 31.[1]

	Stand age				
	15	21	24	27	31
	$Feet^3/Acre$				
Slash	1193	1994	2619	2889	3089
Loblolly	1253	1914	2503	3034	3356

[1] Volume to a 3-inch top using equations from Merrifield and Foil (1967). [1964, 1970: Form Class 67; 1973, 1976: Form Class 72; and 1980: Form Class 77].

DISCUSSION

Slash pine stands in northwest Louisiana grew well yielding 3710 ft^3/acre of total merchantable volume at age 31. By age 15, even though the initial stand stocking rate had been reduced by 44.4 percent, slash pine performance exceeded predicted growth values for an equivalent site index in central Louisiana (Mann, 1971). Foil et al. (1964) reported growth of young slash and loblolly stands at several locations in north Louisiana was comparable with respect to individual tree size and stand volume. Stand growth trends at age 24 corresponded to those reported for thinned slash stands in central Louisiana (Feduccia, 1977). In addition, there was no evidence that the growth of slash pine was more susceptible than loblolly to the detrimental effects of disease, insects, and severe climatic conditions. Thus, artificially established slash pine stands, which were thinned at age 15, have adapted to the growth conditions of northwest Louisiana.

A comparison of periodic changes in stand attributes through age 15 (Tables 1-5) indicates that early growth and development patterns of pure slash and loblolly pine were comparable. Individual tree attributes, DBH and height, were larger in the slash stands, while loblolly stands had greater basal area and volume as a result of higher stocking. After thinning, all stand attributes for the 300 residual slash pines per acre were less than those for loblolly (Table 6). These results, although statistically nonsignificant, suggest that individual slash pine growth and development within a stand was inferior to loblolly pine. Also, it should be noted that during the entire 15-year-growth period slash stocking was nearly 30 percent less than loblolly.

Varying ability of individual slash and loblolly pines to compete for available growing space is illustrated by the growth pattern of stands containing single row mixtures of slash and loblolly (Tables l-5). Initially, high seedling mortality placed slash pine in an unfavorable competitive position. Even though adequate growing space was available, slash pine performance declined continually. Finally, by age 15, the mixed stands were completely dominated by loblolly and the few remaining slash pines were relegated to suppressed positions. Thus, loblolly pine appeared to be the more aggressive species.

At age 31, 16 years after thinning, standing and total merchantable volume yields for pure slash and loblolly stands were 3089 and 3356 ft^3/acre (standing) and 3710 and 4338 ft^3/acre (total). Although volume growth during the 16 year period did not vary by species, the pattern of growth did. This variation in stand growth pattern demonstrates the difference between species with respect to individual trees tolerating competition within the stand. From age 15 to 24, when stand competition was minimal, merchantable growth in the slash stands exceeded loblolly by 14 percent. Slash growth during this period produced 75 percent of the stands growth after thinning, while loblolly produced 60 percent. As competition intensified between ages 24 and 31, slash yields were 82 percent less than loblolly. At age 31, the mean individual tree volume for the largest 100 TPA was 20.77 and 23.25 ft^3 for slash and loblolly, respectively.

CONCLUSIONS

1. Slash pine grown in managed plantations produced acceptible wood yields in northwest Louisiana.

2. Wood yields from managed slash and loblolly pine plantations in northwest Louisiana were comparable.

3. Individual tree growth in managed loblolly pine plantations was superior to slash pine.

4. In northwest Louisiana, slash pine should not be planted in preference to loblolly pine.

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VARIABLE DENSITY YIELD TABLES FOR RED OAK-SWEETGUM STANDS[1/]

Alfred D. Sullivan, Thomas G. Matney, and John D. Hodges[2/]

Abstract.--This paper reports on a study to provide variable density yield tables for red oak-sweetgum stands. Data collection from a total of 150 plots has recently been completed. Preliminary analyses have provided yield equations for cubic-foot and board-foot volumes. Further analysis is planned.

INTRODUCTION

Growth and yield information is vital for making management decisions no matter what the forest type or species. However, such information is extremely scarce for most southern bottomland hardwood types and information based on long-term studies does not exist. The Hardwood Research Council recently listed growth and yield work as a "most urgent" research priority for eastern hardwoods (McLintock 1979).

Normal yield tables have been constructed for individual species such as yellow-poplar (Liriodendron tulipifera L.) (McCarthy 1933), ash (Sterrett 1915, cited by Evans, Burkhart, and Parker 1975) and for upland oaks (Quercus spp.) (Schnur 1937), but such information is not available for most southern hardwood types. The North Carolina State Hardwood Research Cooperative has published data on yields of natural hardwood stands in the southeastern United States. A first report was issued in 1975 (Smith et al.) and a second report (Gardner et al.) presenting improved estimates was published in 1982. The data on which both of these reports are based came from fully stocked stands.

Perhaps the hardwood species for which the most comprehensive growth and yield information is available is yellow-poplar. Diameter distributions and yields for various combinations of site index, age and density for unthinned and largely undisturbed stands of yellow-poplar have been presented by McGee and Della-Bianca (1967) and Beck and Della-Bianca (1970). A 1972 publication by Beck and Della-Bianca presents growth and yield estimates for thinned yellow-poplar stands.

The purpose of this paper is to report on the status of a research project designed to develop variable density yield tables for the red oak-sweetgum (Quercus spp. and Liquidambar styraciflua L.) type. This mixture of two species occurs widely in both major and minor stream bottoms and is of considerable economic importance. Variable density yield tables will be helpful in the management of these stands. In reporting on our project, we will present our data collection methods, provide an overview of the data that are available, present preliminary yield equations, and describe our future plans.

METHODS AND DATA

The effort to develop yield tables for red oak-sweetgum stands represents only one aspect of a larger cooperative research project with the U. S. Forest Service's Southern Hardwoods Laboratory. Under this project, measurements

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have been taken on 150 sample plots in red oak-sweetgum stands. We were fortunate to have the assistance of an experienced hardwood forester on this project. Sample plot locations were selected by Mr. E. C. Burkhardt, formerly Chief Forester of Anderson-Tully Company. Mr. Burkhardt also participated in and supervised field plot measurement.

Selection and Location of Study Plots

Study plot selection was based primarily on stand composition. At least 75 percent of the total basal area of all plots had to be sweetgum or oak species. Further, the sweetgum and oak species group each had to account for at least 20 percent of the total basal area.

For the most part, sample stands were located in minor stream bottoms in central Mississippi. The plots were selected to represent the widest possible range of age, stand density and site quality classes. All plots were located in even-aged stands. Basal area varied from 44 to over 240 square feet per acre, though 98 percent of the basal areas were less than 190 square feet. Age (of the oak species) ranged from 19 to 82 years.

All plots were monumented for relocation with the hope that future remeasurements may be possible. Such data will be extremely valuable and allow development of improved growth prediction systems.

Plot Measurements

Circular measurement plots were used in this study. The plot size in a stand varied so as to capture at least 50 trees but no plot was less than 1 tenth of an acre. On each plot all trees with a DBH of at least 3.5 inches were numbered, tagged, and the following data recorded for each tree:

1. species,
2. DBH,
3. crown class,
4. damage codes (if applicable, e.g., cankered, split, lightning damaged, etc.), and
5. distance and magnetic azimuth from plot center.

On a subsample of ten red oaks, ten sweetgum, and five other species, additional measurements were taken including:

1. total tree height,
2. height to base of the live crown, and
3. crown width.

For each tree containing a number 1, 2, or 3 factory sawlog according to U. S. Forest Service specifications, the length and grade of the first useable sawlog was recorded and height measurements, including total tree height, merchantable height, height to base of the live crown, and heights to 4-, 6-, and 8-inch outside bark diameters, were taken.

YIELD ESTIMATES

Data collection was completed in early October, 1982. Consequently, there has not been much time for data preparation, editing, summarization, and model fitting. Cur preliminary analyses appear promising but all results presented at this time should necessarily be considered tentative.

Cubic foot volumes of sweetgum trees were calculated from equations presented by Reams et al. (1982). Cubic foot volumes of red oak trees were calculated by an equation for southern red oak obtained from the Resources Evaluation Project of the Southern Forest Experiment Station based on work done by Dave Lenhart and associates at Stephen F. Austin State University. Cubic foot volumes of other hardwoods were calculated from a composite equation based on unpublished work of Matney. All cubic foot volumes were calculated to a 4-inch, outside bark top diameter. Board foot volumes of red oak, sweetgum, and other hardwoods were obtained using Girard form class tables assuming a form class of 78. Board foot volumes are expressed in terms of the International ¼-inch log rule.

Analysis for yield estimates was accomplished by using a model previously used by Smith et al. (1975). This model allows prediction of yield from functions of age, total height of merchantable trees, and basal area. Specifically, the model was:

$$\text{Log } V = b_0 + b_1(1/A) + b_2(\text{Log } H/A) + b_3\text{Log } B,$$

where Log = logarithm to the base 10,
V = volume,
A = age of oak,
H = average height of merchantable oak trees, and
B = basal area of all species.

Cubic Foot Yield of All Species

All independent variables of the model for cubic foot yield (all species) were highly significant and the logarithm of cubic foot yield per acre was estimated by:

$$\text{Log CFV(all)} = 1.36 - 33.3(1/A) + 13.7(\text{Log } H/A) + 1.14 \text{ Log}(B)$$

This equation accounted for 92.1 percent of the variation in logarithm of volume with a standard error about the regression line of 0.00267. A plot of predicted values against observed values showed good agreement and a regression of these two variables produced an intercept of zero and a slope coefficient of one.

Board Foot Yield of All Species

Data from the 148 plots having board foot volumes greater than 0 were used to fit the model for board foot volume yields. All independent variables of the yield model were highly significant and logarithm of board-foot yield is estimated by:

$$\text{Log } BFV(all) = 2.17 - 124.(1/A) + 51.5(\text{Log } H/A) + .972 \text{ Log } B.$$

This equation accounted for 70.8 percent of the variation in logarithm of yield with a standard error about the regression of 0.0523. Again, a plot of observed versus predicted values showed close agreement and a regression of these two variables produced an intercept of zero and a slope coefficient of one.

Cubic Foot and Board Foot Yields of Oak

In an effort to explore the possibility of projecting yields of individual species in this type, an equation was fitted to predict cubic foot yield of the oak species group. The model fitted was the same as given above with the addition of Log(BAO/B), where BAO is the basal area per acre in the oak species group. Once again all coefficients were highly significant and logarithm of cubic foot yield of oak is estimated by:

$$\text{Log } CFV(oak) = 1.36 - 41.8(1/A) + 19.7(\text{Log } H/A) + 1.15 \text{ Log } B + 1.09 \text{ Log}(BAO/B).$$

This equation accounted for 98.2 percent of the variation in logarithm of cubic foot yield of oak with a standard error about the regression of 0.00121.

The same equation model was fitted for board foot volume. All coefficients were highly siginificant and board foot volume of oak is estimated by:

$$\text{Log } BFV(oak) = 2.38 - 188.(1/A) + 89.0(\text{Log } H/A) + .795 \text{ Log } B + .738 \text{ Log } (BAO/B).$$

This equation accounted for 68.2 percent of the variation in logarithm of oak board foot yield and had a standard error about the regression line of 0.0563.

CONCLUSION

As mentioned earlier, these results are based on our preliminary analyses and are considered tentative at this time. However, the results appear promising and lead us to believe that we can provide useful information for the red oak-sweetgum type which is widely dispersed throughout Southeastern forests. This information should be a valuable management tool for foresters and landowners making decisions about stands like those considered in this study.

We plan to make additional analyses of the data obtained in this work. In addition to consideration of alternative models for predictions presented in this paper, we will examine site index prediction, basal area growth and biomass predictions for these stands.

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RATE OF **RETURN** FROM FERTILIZATION OF SEMIMATURE

SLASH **PINE** PLANTATIONS[1/]

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Abstract.--Fertilization trials were established with semimature slash pine plantations on 5 soil groupings. Eight treatments in a 2 by 4 factorial with phosphorous and nitrogen were broadcast on the plots. Individual tree volume and diameter growth equations were estimated for both 5 and 8 years after treatment. **Stumpage** products production, differentiated by merchantability limits and value per cubic foot, were estimated for each treatment and soil type. The rate of return was estimated for each combination of outputs and length of investment. The results from this series of fertilization trials indicates that the profitability of treatment, as measured by rate of return, varies by soil **group**, length of investment, and mixture of merchantable products.

INTRODUCTION

Forest fertilization has increasingly been recognized as a silvicultural tool for expanding fiber yields from pine plantations in the southeastern coastal plain. By mid-1978, approximately **900,000** acres in the South had been treated with some type of fertilizer with continuing treatments predicted at a rate of 250,000 acres per decade (Bengtson 1979). Since the early work by Pritchett **(1961),** most of the scientific analysis of fertilization in the coastal plain region has focused on the treatment at stand establishment and the nutrient requirements of various southern yellow pine species. More recently (Fisher and Garbett 1980) determined that the probability and magnitude of growth response of semimature slash pine **(<u>Pinus elliotti</u>** var. **<u>elliottii</u>** Engelm.) varies from site to site. They developed morphological soil groupings which were found to provide a means to better estimate fertilizer response of slash pine. Their soil groupings are presented in Table 1 as, part of the Cooperative Research in Forest Fertilization (CRIFF) program at the University of Florida.

Although it is **valuable** to know that **commercial** tree species will respond to fertilization at stand initiation or at mid-rotation, of fundamental importance to management is treatment profitability. Moderately high growth rates were found to cause no **deterioration** of important wood properties (Gentle et al. **1968),** thus accelerated volume growth can be used for the same product and thereby command equivalent market prices as normal volume.

Among the numerous studies which have examined the profitability of forest fertilization is a recent regional analysis by Fight and Dutrow (1980). They developed estimates of before-tax real rates of return on fertilization of **Douglas**-fir in the Pacific Northwest and slash pine in the Southeast. Although the real rates of return varied by species, broad soil type, and timing, the top rates were near 30% in both regions. This study is useful in explaining why certain lands should be **fertilized,** but their analysis ignored the price differentials of resulting **larger-dimensioned** stock. Such price differences occur because large diameter **stemwood** can be utilized in relatively higher valued primary or secondary products than smaller diameters.

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Given that the volume growth response of slash pine varies by soil group and number of years between treatment and harvest, it was hypothesized that the **stumpage** product mix varies also because of the resulting different diameter class distributions. This analysis was designed to demonstrate the before-tax rate of returnfrom semimature slash pine fertilization return from semimature slash pine fertilization for various soil groups, fertilizer mixes, and output combinations.

treatments were arranged in a 2 x4 factorial with phosphorous (P) at 0 and 50 pounds per acre and nitrogen **(N)** at 0, 50 100 and 200 pounds per acre. The fertilizer was broadcast on the plots, N in the form of urea and P in the form of concentrated super phosphate.

At the time of fertilization, the breast height diameters of all trees in each plot were measured. Additionally, the heights of six randomly **slected** trees were measured on each plot

Table 1.
CRLFF Soil Groups

Soil groups	Drainage class	B Horizon	Subgroups equivalents
A (fine-textured savanna soils)	Very poorly to somewhat poorly drained	No spodic horizon; argillic within 5Ocm	Typic and Plinthic Aquults
B (coarse-textured) savanna soils)	Very poorly to somewhat poorly drained	No spodic horizon; argillic below 5Ocm	Arenic and Grossarenic Aquults, Aquents and Aquepts
C (ultic flatwoods soils)	Very poorly to somewhat poorly drained	Spodic and argillic present	Ultic Aquods and Humods
D (typic **flatwood** soils)	Poorly to moderately well drained	Spodic but no agrillic horizon	Typic, **Aeric,** and Arenic Aquods and Humods
E (fine-textured upland soils)	Moderately well to well drained	No spodic horizon; agrillic below 5Ocm	Typic and Plenthic Uldulta Typic and Typic and Plinthic Uldulta
F (coarse-textured upland soils)	Moderately well to well drained	No spodic horizon; argillic below 5Ocm	Arenic and Grossarenic Udults Umbrepts and Ochrepts
G (dry sands)	Somewhat excessively to excessively drained	No spodic horizon; argillic may or may not be present	Psamments

METHODS

The fertilization trials were established in semimature (15 to 18 years of age) slash pine. Blocks of 8 treated plots each were divided as plantations in Georgia and Florida. Forty-five blocks of 8 treated plots each were divided as follows among 5 soil groups:

Test Block Distribution

Soil Group	Number of Blocks
A	6
B	10
C	10
D	5
F	14

The total number of blocks was constant **over** the **5-** and **8-year** investment periods. The 8 treatments

and regression equations were developed to predict the volume from measured DBH for every tree and each plot. Tree **DBH** and height for all trees on each measurement plot were measured after 5 and after 8 growing seasons. Volume per tree outside bark to a **3-inch** top was calculated for all **measured** trees using the measured DBH and height in the volume formula from Bennett et al. (1959).

A polynominalregression equation with the treatment levels of N and P, and the original tree's volume or DBH (Volo and **DBHo,** respestively) measurement was developed (via ordinary least squares). Equations were estimated predicting individual tree volume and DBH at 5 and 8 years after fertilization. A different equation was estimated for each of the 5 soil groups.

By using the prediction equations discussed above, volume and DBH for each individual tree at both 5 and 8 years for each of the 8treatments was predicted by substituting into prediction equations the appropriate values for N, P, Vol_o and DBH_o The predicted values were then assigned to diameter classes within each treatment based on the predicted diameters. Finally, the total predicted volume for each diameter class for each treatment was calculated by summing the individual tree predicted volumes in that diameter class for that treatment.

Three stumpage product types were chosen to emphasize the price differentials which affect forest fiber investment. Although markets in the southeastern coastal plain utilize forest stumpage for more than just pulpwood, chip-n-saw and lumber these products represent a common range for the material being harvested at about age 20 through 26. Stumpage prices vary monthly although their general trend has been steadily upward. Because of this, the 1981 average price for each product was used to reduce the possible bias in the analysis of non-normal prices.

The semimature stands ranged between 15 and 18 years of age at treatment with five to eight growing seasons thereafter. The estimated cubic root volume was converted into cords based on the assumption that 90 solid cubic feet was equivalent to a stand cord. Cubic foot volume was also converted to Scribner board feet to estimate lumber equivalents. Stumpage values were estimated via quotations from Timber-Mart South, an independent price report. Averaged 1981 stumpage prices for south Georgia and northeast Florida were used. The estimated stumpage values and their merchantability limits are as follows:

Stumpage Values by Merchantability Limit

Product	Stumpage Value	Diameter B east
Pulpwood	$27.43/cord	All estimated volume
Chip-n-saw	$35.18/cord	Volume of trees >6"DBH
Lumber	$156.09/MBF	Volume of trees >8"DBH

The lowest cost fertilizer material and application methodology were utilized for each treatment since previous work (Pritchett and Comerford 1982) has demonstrated that the source of phosphorus is not an important factor in the growth response of slash pine over a 5- to 20-year period after treatment. The fertilizer and application costs were developed from an average based on a range of prices obtained from suppliers in January, 1982. The lowest treatment costs were employed, and are listed below:

Average Lowest Cost Treatments

Treatment Material	Treatment/ac.	Cost/ac.
Rock Phosphate	50 lbs. P	24.12
Urea	50 lbs. N	18.47
Urea	100 lbs. N	36.94
Urea	200 lbs. N	73.88
DAP	50 lbs. N + 50 lbs. P	36.14
Urea and Rock Phos.	100 lbs. N + 50 lbs. P	61.05
Rock Phos.	200 lbs. N + 50 lbs. P	98.00

The average 1981 stumpage prices and the January 1982 fertilization cost quotes were assumed to exist in the same time frame for the purposes of this anlaysis. Since early 1982 stumpage prices were approximately equal those prices recorded in 1981,the average prices were used. The fertilization prices have been highly variable and cyclical in nature. Therefore, the analysis was based on the assumption that treatments could have been made at the prices listed last spring. The before-tax rate of return was calculated utilizing the estimated volume response, its value and the cost of treatments via the formula from Davis (1962):

$$i - n\sqrt[n]{\frac{Vn}{Vo}} - 1$$

where: i equals the before rate of return on investment
Vn is the value of the growth response to treatment
Vo is the cost of the fertilization treatment
and n is the length of time of investment, or the number of growing seasons after treatment.

The equation calculated a real, before-tax rate of return. The rate is a function of treatment cost, estimated response, stumpage prices and the length of investment. The rate of inflation and its impact on costs or prices are ignored as are any other management activities. The analysis compares fertilizer treatment response in terms of real dollars, (ie, with the inflation of etumpage prices over time removed). The actual real rate of increase for southern yellow pine and southeasterm softwood pulpwood prices were estimated at only approximately 1 percent annually, based on statistics from USDA, Forest Service (1981). Therefore, the estimated rates are conservative in nature since the annual 1 percent price increases are Southwide and can be highly variable depending on long-term local market conditions.

RESULTS

The signs for the estimated coefficients of the independent variables are shown in Table 2. Soil Group A was characterized by a linear response to the quantity of P applied. Nitrogen was not a significant independent variable in any of the, equations estimated in this soil group. The combination of variables for the estimated equations for Soil Group B demonstrate a greater complexity of interactions. Both N and P demonstrate linear and interactive relationships while the level of N also displayed a nonlinear effect in the equations.

The significant independent variables in the estimated equations for Soil Group C are also a complex array of polynomial permutations. Again, the levels of N and P, their interaction, and the nonlinear significance of N determine the values of the dependent variables. The results for Soil Group D show that the original values are of greater predictive importance than are the levels of N and P. The estimated future equations for Soil Group F demonstrate predicted fertilizer response whereas future volume equations are only affected by the treatment level of P for the longer investment period.

Assuming the individual tree volumes to be normally distributed, 95 percent confidence intervals about the mean predicted total volume per acre were calculated and are presented in Table 3. The data in this table represent the estimated total volume production for slash pine on five soil groups, eight fertilizer treatments and two investment periods. The estimates are based on the biological responses and the statistical analysis used to fit polynomial functional forms to the observations. The estimation equations of individual tree volume and diameter breast height,facilitated the development of the stand diameter and volume distribution for each combination of soil, fertilizer and time.

Tables 4 through 7 list the treatments by soil group which resulted in postive rates of return for product combinations. The before tax rates of return are listed for both investment periods and each combination of **stumpage** products. The largest rate of return for either five- or eight-year investment periods was determined to occur with 50 pounds of phosphorous per acre on the fine-textured savanna soils (Table 4). The increase in harvest value due to increased yields of lumber and pulpwood resulted in a rate of return of over 36 percent, compounded annually for five years. The rate declined to 27 percent for the longer eight year investment which resulted in expanded lumber and chip-n-saw yields. Although Table 3 indicates that increased volume yields occur over eight growing seasons following treatment as compared to five, Table 4 demon-

Table 2
Signs of Estimated Coefficient for Volume and DBH Equations

Soil Group	Estimates	Volo	DBHo	N	P	NP	N^2	N^2P
A	DBH_5	0	+	0	+	0	0	0
	Vol_5	+	0	0	+	0	0	0
		0	+	0	+	0	0	0
	DBH_8	+	0	0	+	0	0	0
B	DBH5	0	+	+	0	0	+	0
	vo15	+	0		+	0	+	0
	DBH_8	0	+		+		+	+
	Vol_8	+	0		+	0	+	0
C	DBH	0	+	+	+	0	0	0
	Vol_5	+	0	+	+	+	+	-
	DBH_8	0	+	+	0	0	+	0
	Vol_8	+	0		+	+	+	
D	DBH	0	+	0	0	0	0	0
	Vol_5	+	0	+	0	0	0	0
	DBH_8	0	+	0	0	0	0	0
	Vol_8	+	0	0	0	0	0	0
		0	+	+		+	0	0
	DBH_5	+	0	0	0	0	0	0
	DBH_8	0	+	+	+		0	0
	Vol_8	+	0	0	+	0	0	0

Table 3
Predicted Volume/Acre (ft^3/ac.)

Soil Group (year)	Treatments (lbs/ac) 0N 0P	50N 0P	100N 0P	200N 0P	0N 50P	50N 50P	100N 50P	200N 50P
(Nitrogen) (Phosphorus)								
A_5	2842±66 →	→	→	→	3065±67 →	→	→	→
A_8	3472±92 →	→	→	→	3799±98 →	→	→	→
B_5	2315±66	2300±50	2311±50	2415±68	2425±68	2410±50	2422±58	2525±69
B_8	2956±117	2888±90	2877±105	3028±121	3104±118	3037±88	3026±103	3177±123
C_5	1706±55	1722±35	1751±45	1751±45	1851±54	1803±35	1861±44	1923±57
C_8	2222±98	2229±63	2262±80	2399+98	2253±97	2337±64	2401±80	2473±100
D_5	1457±69	1525±33	1592±30	1726±55	1457±46	1525±33	1592±30	1725±55
D_8	2049±69 →	→	→	→	→	→	→	→
F_5	1832±34 →	→	→	→	→	→	→	→
F_8	2289±64 →	→	→	→	2370±65 →	→	→	→

strates that the before-tax rate of return actually declines.

Table 4
Soil Group A
Before-Tax Rate of Return
by investment period[1/]
(percent)

Sale Basis	Five Years	Eight Years
Pulpwood (P.)	23.2	19.4
Chip-n-saw (CnS.)	26.3	23.5
Lumber (L.)	23.6	18.6
CnS plus P.	28.6	23.2
L. plus P.	36.3	25.8
L. Plus CnS.	33.4	27.6
L. plus CnS. and P	35.9	27.4

1/ Treatment was composed of 50 lb. P per acre.

The coarse-textured savanna soils, Soil Group B (Table 5), demonstrate a reduced and more variable response to fertilization than do the fine-textured savanna soils. These soils respond to both nitrogen and phosphorus fertilization. The volume growth response is greatest for the treatment of 50 pounds of P and 200 pounds of N per acre. The additional growth due to the nitrogen is insufficient to offset the greater costs incurred so that the preferred treatment under current assumptions remains the 50 pounds of phosphorus per acre with a maximum before-tax rate of return of 15 percent. Although the preferred treatment level is the same for these two types of savanna soils, a longer investment period (eight years) yields a greater rate of return for the coarse-textured soil. The predicted rate of volume and value growth for eight growing seasons exceeds the rate of increase for the carrying cost of the treatment.

The ultic flatwood soils, or Soil Group C (Table 6), exhibit an even greater growth response to nitrogen fertilization than do the previous two soil groups. As the nitrogen component of the treatment is increased, greater volume production can be expected (Table 3). The 50 pounds P plus 50 pounds N per acre treatment for the five-year investment is preferred. This reflects the more rapid cost expansion incurred by increasing the amount of N applied in relation to the increase in added values. If the goal of management is the production of large trees, then the eight-year investment is desirable and nitrogen applied at the rate of 200 pounds per acre would result in the better before tax rate of return. The main effect of the fertilization treatments is not just additional volume growth but the distribution of additional volume in the larger DBH classes. Note that if pulpwood production was the sole fiber product desired by management then fertilization would not result in net profits with the given set of base assumptions. For both investment length alternatives, the increases in volume in the 6 to 8 inch DBH classes causes the favorable net profit result.

Phosphorus fertilization alone, or with nitrogen, was found to be inefficient on the typic flatwoods soils, Soil Group D (Table 7). The use of nitrogen fertilizer increased volume growth but at a linear rate. Higher rates of application per acre resulted in expanded harvest volume but also expanded costs. The cost of nitrogen is relatively low, 18.47 dollars per acre for 50 pounds of N per acre, which is less than the value of the resulting increased volume growth. This soil group is not very growth responsive, but is sufficiently responsive to the nitrogen application that a positive before-tax rate of return results from a five-year investment. The coarse-textured upland Soils Group F demonstrated practically no positive rates of return for the costs and revenue variables assumed in this analysis. This is a direct result of the virtual unresponsiveness of this soil group to any of the treatments listed in Table 3.

DISCUSSION

The responses of the two savanna soils differ on the length of investment with the coarse-textured soil growth response greater for the eight-year investment. The fine-textured soil demonstrated the opposite interaction. The results indicate that the fine- and coarse-textured savanna soils can return a profit with fertilization. Only phosphorus is justified on the phosphorus deficient Soil Group A. The soils in Group B do not exhibit as great a P deficiency, but growth was stimulated with both phosphorus and nitrogen. Although nitrogen increases production, the before tax rate of return is greater for phosphorus alone because of its lower cost in relation to the corresponding increase in stumpage value produced.

The ultic flatwoods soils (Group C) responded to both nitrogen and phosphorus. Again, although volume production steadily increases with the rate of nitrogen applied, the cost of investment increased at a more rapid rate. The combination of 50 pounds of N and P each resulted in the largest rate of return on investment for both time periods. The price differentials on stumpage production and the change in the diameter/volume distribution at harvest have an important interaction. In this example, fertilization of this type of stand would not be very efficient since the production of pulpwood or lumber is insufficient to offset cost. It is the movement of more trees from the below six inch DBH classes to the 6 to 8 inch classes which results in a greater per volume unit price (chip-n-saw) and a favorable rate of return.

The typic flatwood soils (Group D) are the only group which demonstrate non-growth respons-

Table 5
Soil Group B
Before-Tax Rate of Return
by
Investment Period and Treatment

Length of Investment	Sales Basis	pounds/acre							
		0	0	0	50	50	50	50	Phosphorus
		50	100	200	0	50	100	200	Nitrogen
Five Years	Pulpwood (P.)	-	-	-	6.8				
	Chip-n-Saw (CnS.)	-	-	-	1.0			0.0	
	Lumber (L.)	-	-	-					
	CnS. plus P.	-	-	-	10.5		6.8		
	L. plus P.	-	-	-	10.3			0.4	
	L. plus CnS.	-	-	4.3	3.8			7.8	
	L. plus CnS. and P.	-	-	-	12.5			5.9	
Eight Years	Pulpwood (P.)	-	-	-	8.1				
	Chip-n-Saw (CnS.)	-	-	-	7.1				
	Lumber (L.)	-	-	-	10.7			5.0	
	CnS. plus P.	-	-	-	10.7				
	L. plus P.	-	-	-	14.7	0.7		5.3	
	L. plus CnS.	-	-	-	12.3			5.2	
	L.plus Cns. and P.	-	-	-	15.0	1.8		5.4	

- nonpositive rate of return

iveness to phosphorus and positive responsiveness with the application of nitrogen alone. The estimated individual tree volume and DBH equation5 are both linear so that cubic foot production increases as the amount of nitrogen increases, as do the costs. Essentially, the point of diminishing returns to nitrogen has not been determined for the levels tested. The steady decline in rates are due more to rounding error5 in the estimation of stumpage value by product type and volume by diameter class distribution, than to actual revenue/cost interactions.

The estimated tree volume and DBH equations for the coarse-textured upland soils indicated little if any growth response to fertilization. In general, given the economic assumptions made in this study, F-group soils are not favorable sites for treatment.

The eight-year growth responses may actually be underestimated because of the design and on-ground layout of the test blocks. Cross-feeding appears to have increased the growth on the control plots. Therefore, the before-tax rate of return for the eight-year investments of fertilizer treatment5 are conservative estimate5 since the growth differential may have been greater than those recorded. New tests are currently in place by CRIFF to test if, and to what extent, the long-term aspects of fertilization investment differ from previous tests.

This type of analysis is very dependent on the costs, revenues and stumpage product diameter merchantability limit5 assumed. Based on the formula used in the analysis, a fertilizer price increase will result in a slightly greater decrease in the before-tax rate of return. A decline in stumpage prices has the same effect on

Table 6
Soil Group C
Before-Tax Rate of Return
by
Investment Period and Treatment

Length of Investment		Sales Basis	pounds/acre							
		Phosphorus	0	0	0	50	50	50	50	Phosphorus
		Nitrogen	50	100	200	0	50	100	200	Nitrogen
	Five Years	Pulpwood (P.)								
		Chip-n-Saw **(CnS.)**	12.2	8.2	5.4	7.1	12.0	3.8	6.4	
		Lumber (L.)				5.1	-	-	-	
		CnS. plus P.					3.8	0.8	-	
		L. plus P.					3.8	2.6	-	
		L. plus **CnS.**	12.2	11.7	8.6	12.1	15.3	7.9	9.4	
		L. plus **CnS.** and P.	-	-	1.9	-	8.2	5.4	3.4	
	Eight Years	Pulpwood **(P.)**								
		Chip-n-Saw **(CnS.)**			3.6	-	-		2.1	
		Lumber (L.)			3.8	-	-		0.6	
		CnS. plus P.			0.4	-	1.5	0.5	0.5	
		L. plus P.			4.4	-	0.4	2.7	3.4	
		L. plus **CnS.**			7.7	-	-		5.7	
		L. plus **CnS.** and P.			5.3	-	2.0	3.1	4.5	

- nonpositive rate of return

the rate except that the impact is slightly more pronounced. The reverse price changes of cost or revenues exhibit the same relationships with the rate of return, but in the opposite direction for both cases. In general then, the longer the investment period, the less sensitive the rate of return becomes to variations in the revenue/cost ratio.

In general then, a mixture of **stumpage** products is more profitable than any single product because of the price differentials available to larger dimensioned stumpage. The more efficient use of forest fiber through the division into multiple products results in a higher average value per cubic foot of volume.

Before-tax rates of return are estimated because of the extreme variability of tax rates and the criteria used to deduct management costs (capitalizing or expensing) from profits. Forest Industry faces different rates of taxation on profits than do individuals. Each are probably able to elicit capital gains treatment for their **stumpage** derived revenues. Any tax on the increased growth will reduce the rate of returns on investment. The reduced tax under capital gains lessens the reduction via a smaller tax rate. If the cost of treatment is expensed, this reduces the tax burden in the year of treatment and the net result is a higher after-tax rate of return than the **before-**tax rate. Time, taxation rates at treatment and at harvest and the assumed investment rate all impact on the expensed rate of return. Since capitalization and expensing cannot both be incorporated by an operating entity, one or the other must be selected. The after-tax cost was ignored by this analysis in order to reduce the complexity of the problem to manageable proportions.

Table 7
Soil Group D
Before-Tax Rate of Return
by
Investment Period and Treatment

	pound/acre							
	0	0	0	50	50	50	50	Phosphorus
Sale Basis	50	100	200	0	50	100	200	Nitrogen
Pulpwood (P.)	2.2	2.2	2.1	-	-	-	-	
Chip-n-Saw			-	-	-	-	-	
Lumber (L.)					-	-	-	
CnS. plus P.	4.8	4.6	4.5	-	-	-	-	
L. plus P.	3.1	2.9	2.8	-	-	-	-	
L. plus CnS.					-	-	-	
L. plus CnS. and P.	4.7	4.8	4.7	-	-	-	-	
Pulpwood (P.)			-	-	-	-	-	
Chip-n-Saw (CnS.)			-	-	-	-	-	
Lumber (L.)			-	-	-	-	-	
Cns. plus P.			-	-	-	-	-	
L. plus P.			-	-	-	-	-	
L. plus CnS.			-	-	-	-	-	
L. plus CnS. and P.					-	-	-	

- nonpositive rate of return

CONCLUSIONS

The data from this series of fertilizer trials demonstrate that the before-tax rate of return varies by soil group, level of fertilization and the product mixture at harvest. The estimated profitability of forest fertilization depends not only on the predicted growth response, but also on the value of products produced, the cost of treatment and the length of investment period. The savanna type soils groups represent the better fertilizer investment alternatives for semimature slash pine stands. Considering that these are real rates of return, over and above the inflation rate, then fertilization on the **flatwood** soils appears to be profitable at this time.

These results are intended to provide a procedure for assisting individuals in the calculation of the profitability of fertilizing their semimature slash pine stands. Their decision should be based on the **stumpage** diameter distributions which are desired, the price differentials prevailing, costs of treatment and the expected growth response.

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EVALUATING REGENERATION SUCCESS

IN PLANTATIONS USING DISTANCE SAMPLING[1/]

W. D. Smith[2/]

Abstract.--Nearest neighbor and nearest tree sampling have been frequently suggested for regeneration and other density surveys. Its applicability has been limited to conditions of random spatial pattern. If expanded to the 4th rather than first nearest neighbor the expected distance for uniform and randomly distributed populations is approximately equal. Plantations can be described as uniform populations with random variation in density. Under those conditions the distance to the fourth nearest neighbor is an efficient estimator of density.

INTRODUCTION

Approximately 1.2 million acres are planted annually in the southern United States by industrial, private, and public agencies. Regeneration surveys account for a significant contribution to the cost of managing these acres. An alternative that would substantially lower the cost of plot survey techniques would be desirable. This paper presents a generalization of the nearest neighbor method that could be applicable to plantations.

Nearest neighbor and nearest tree sampling are frequently suggested for regeneration and other density surveys. The procedure, to measure the distance from a subject tree to its nearest neighbor or from a point to the nearest tree, is simple, rapid,3 and relatively free of measurement error. Unfortunately its applicability has been limited to populations with a random spatial pattern. A pattern which occurs infrequently in nature (Schreuder, 1978) and not at all in plantations.

DISTRIBUTION OF NEAREST NEIGHBORS

Clark and Evans (1954) developed a procedure for testing for randomness of spatial pattern using the ratio of the mean distance to the nearest neighbor to the expected distance given a randomly distributed population. Morisita (1954) derived the same formula and pointed out the increased accuracy of density determination if second, third, etc. nearest neighbors are included. Thompson (1956) extended the Clark and Evans derivation to obtain the expected distance to the nth as well as first nearest neighbors for randomly distirbuted populations

The expected distance to the nth nearest neighbor given a randomly distributed population is (from Thompson 1956).

$$E(r_n) = \frac{1}{\sqrt{m}} \frac{(2n)!n}{(2^n n!)^2}$$

where m is the density per unit area.[4] From the above the density per unit area, m, can be found by

$$m = \left[\frac{1}{\bar{r}_n} \frac{(2n)!n}{(2^n n!)^2}\right]^{1\ 2},$$

where $\bar{r}$ is the average distance to the nth nearest neighbor. Trees per acre is obtained by multiplying m by 43560. Values for n equal to 1 through 6 are presented in Table 1.

1/ Paper presented at Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, Nov. 4-5, 1982.

2/ Lecturer of Forestry, N.C. State University, Raleigh, NC.

3/ Personal communication with one forest products firm indicated a threefold decrease in sampling time.

4/ Unit area = square of unit of measurement for $\bar{r}_n$, e.g. a square foot or square meter.

Table 1.--Expected density given average distance to the 1st through 6th nearest neighbor for a a random population.

n	1	2	3	4	5	6	
$\sqrt{m}$	$\frac{.5000}{\bar{r}_1}$	$\frac{.7500}{\bar{r}_2}$	$\frac{.9375}{\bar{r}_3}$	$\frac{\quad}{r_4}$	$\frac{1.0937}{\bar{r}_5}$	$\frac{1.2616}{r_6}$	1.3820

The above relationships are for randomly distributed populations, Both Morisita and Thompson express doubt about the applicability of such techniques for non-random populations. However consider the opposite extreme. For uniformly distributed populations (i.e. hexagonally arranged) all individuals are equidistant from their six nearest neighbors. In this case the expected distance between individuals is

$$E(r_n) = \frac{1.0746}{m} \text{ for } n = 1 \text{ through } 6$$

and density per unit area, given the mean distance, is

$$m = \left(\frac{1.0746}{n}\right)^2 \text{ for } n = 1 \text{ through } 6$$

APPLICATION TO PLANTATIONS

Plantations can be spatially described as uniform populations with random variation in density (Smith, 1977). The expected value of the average distance scaled by the square root of density for the six nearest neighbors in uniform and in random populations is presented in figure 1. At n = 4, the scaled distance is approximately equal for both random and uniform populations. Figures 2 and 3 present the observed scaled mean distances and their standard deviations for four mapped plantations. In general the actual distances are greater than expected, if random, for $n<4$ and leas than expected, if random, for $n>4$. In general, the standard deviation is at its minimum for n = 4.

From the above observations it is inferred that the expected scaled distance to the 4th nearest neighbor is approximately equal for spatial patterns that vary from uniform to random. Based on that inference the density for plantations can then be extimated using the relationship

$$m = \left(\frac{1.0937}{\bar{r}_4}\right)^2$$

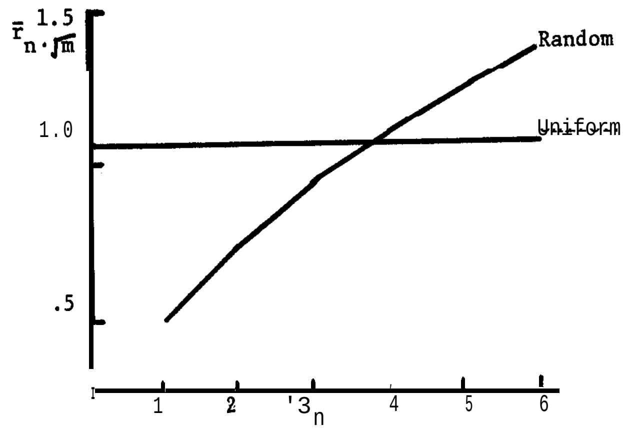

Figure 1.--Relationship between the expected distance to the six nearest neighbors for random and uniform populations.

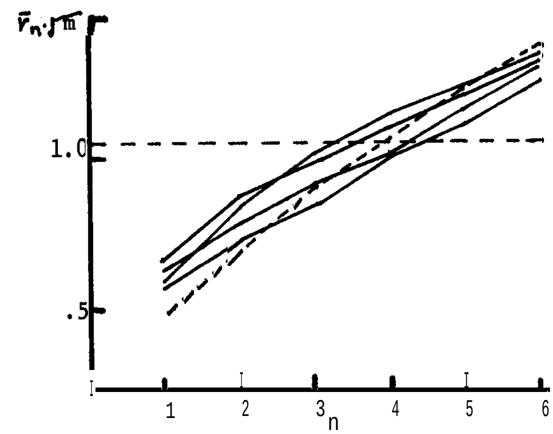

Figure 2.--Observed mean distance to six nearest neighbors for 4 mapped plantations.

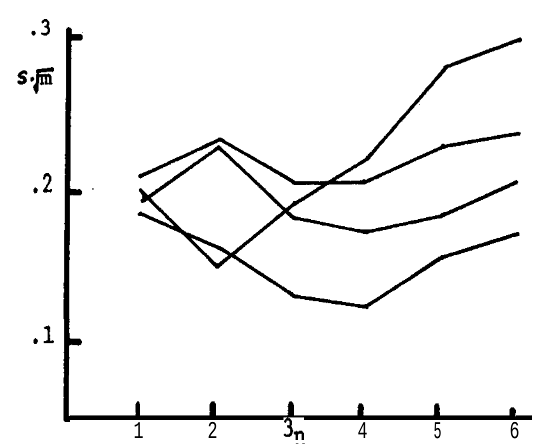

Figure 3.--Observed standard deviation of distance to six nearest neighbors for 4 mapped plantations.

RESULTS AND DISCUSSION

The procedure was evaluated by simulating both 1/50 acre fixed plots and the distance to the 4th nearest neighbor using the four mapped plantations. The results of 10 samples of 15 observations are presented in Table 2. The method has had limited field testing with comparable results (Table 3).

A concern during field sampling was the problem of identifying the fourth nearest neighbor. Without excessive measurement time. However by the time the crews had measured a minimal number of trees they became quite proficient identifying the fourth nearest neighbor with only occasional checking. The problem is somewhat alleviated by the characteristic that when survival is poor identification is easy and that when survival is high error caused by mis-identification is small. The major limitation in its application is under extreme rectangular spacing (greater than 2 to 1). The spacial pattern in that case is clumpy under that condition and does not fall between random and uniform.

Table 2.--Results of simulated plot and distance sampling using 4 mapped plantations

Stand #	Actual Trees/ Acre	Estimate Using Trees/ Acre	1/50 acre plots s.d.	Estimate Using Trees/ Acre	$\bar{r}_4$ s.d.	n
1	568	563	129	544	202	15
2	181	184	81	214	82	15
3	190	176	72	225	110	15
4	508	503	144	477	124	15

Table 3.--Results of field evaluation of plot and distance sampling

Sample #	Estimate Using Trees/ Acre	1/50 acre plots s.d.	Estimate Using Trees/ Acre	$\bar{r}_4$ s.d.	n
1	531	53	515	52	17
2	402	46	320	36	12
3	338	51	299	41	18

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APPROXIMATING THINNED STAND DIAMETER DISTRIBUTIONS

WITH STATISTICAL PROBABILITY FUNCTIONS[1/]

T. G. Matney and A. D. Sullivan[2/]

Abstract.--A method of applying the three parameter Weibull probability distribution and truncations of the distribution to estimate thinned stand diameter distributions is explored. The three parameter Weibull distribution is used to obtain stand diameter distributions prior to first thinning. Estimates of residual stand diameter distribution following thinning are determined using either an untruncated or a truncated three parameter Weibull distribution; the distribution used depending on the characteristics of the thinning process. Diameter distributions are grown through the application of a transformation that regenerates untruncated and truncated Weibull distributions. Diameter distributions for additional thinnings are calculated in the same fashion as for the first thinning. Parameter estimates of the required distribution and transformation are obtained using a combination of regression equations, parameter recovery procedures, and knowledge about the thinning process.

INTRODUCTION

Probability distribution functions have been applied successfully in describing size class distributions of unthinned pine plantations through time (Clutter and Bennett 1965; Smalley and Bailey 1974a and b; Lohrey and Bailey 1977; Dell et al. 1979; and Feduccia et al. 1979). These models were developed in response to the early 1960's and 1970's philosophy that plantations would provide primarily short rotation pulpwood. Thinnings in such a system are rarely practical, since there is no clear gain in fiber yield. In recent years, however, the abundant supply of high quality veneer and sawlogs from natural stands has steadily declined. With this decline, managers are looking toward plantations for production of high quality sawlogs as early as possible. Thinnings are an integral part of any silvicultural system where emphasis is on sawlog products. Hence, there is now a greater need for models to predict size class distributions of repeatedly thinned stands.

The purpose of this paper is to describe a flexible modeling framework developed for approximating diameter distributions of repeatedly thinned stands. While specific results given apply only to thinned old field plantation loblolly (*Pinus taeda* L.) stands, the method presented could be used to model other species and stand conditions.

DATA

The data for this study were the combined data from two permanent plot studies of old-field plantation grown loblolly pine: a United States Forest Service (USFS) thinning study and a Mississippi State University (MSU) spacing study. The USFS data were derived from a number of studies conducted to determine the effect of site quality, stand density and thinning on the growth and yield of loblolly

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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pine plantations located in Ashley County, Arkansas; Lafayette and Yalobusha Counties, Mississippi; and Henderson and Madison Counties, Tennessee. The Madison County plots were established in 1929 to demonstrate that loblolly pine could grow and do well in that area. The other plots were established prior to World War II in stands planted to control the erosion of old fields. All stands were planted at initial stand densities greater than 1000 stems per acre.

Except for some control plots, the plots were repeatedly thinned, mostly on a 3- to 5-year cycle. Treatments tested were precommercial thinning at age 9; thinning by removing every third and fourth row; D + six thinning; and thinning to residual basal areas of 70 to 120 square feet of basal area per acre. Excluding the row thinnings, all thinnings were from below.

Data recorded were the frequency and height by l-inch DBH classes, before and after thinning, for all trees 1.5 inches DBH or larger. The USFS data were from 74 permanent plots, providing sufficient observations of stand conditions to calculate 623 yield values and 299 growth values. Base age 25 site index ranged from 55 to 78 feet for the plots -- calculated from the average height of trees in the largest DBH class at the age closest to base age using the site index equation presented by Lenhart (1971). Plot ages ranged from 9 to 34 years. Basal areas on the 12 uncut plots varied from 118 square feet per acre at age 14 to 204 square feet per acre at age 30. Square feet of basal area per acre before thinning ranged from 53 to 173.

The MSU spacing study[3/], established on the MSU School Forest[4/] in the winter of 1959, was designed to investigate the effects of spacing on stand development. A randomized complete block experimental design was used with four replicates of each of the six spacings (ft. x ft.): 5 x 5, 5 x 6, 6 x 6, 6 x 7, 7 x 8, and 9 x 10. The spacing treatments were planted in one acre rectangular plots with a designated central half acre measurement plot. The seedlings were of grade two or larger and were produced from a local seed source.

The data recorded relevant to this study are the DBH of surviving trees and the DBH and height pairs of 15 trees uniformly distributed across diameter classes at ages 8, 10, 12, 14, 15, 17, 19, and 20. Across all ages, replicates and spacings the observations provided for the calculation of 192 yield values and 168 growth values.

The site index (base age 25) for the 24 study plots averaged 80 feet and ranged from 76 to 83 feet. Site index values for each plot were obtained from the average height of dominant and codominant trees at age 20 using the same site index equation used for the USFS study. Square foot basal areas per acre at age 8 varied from a minimum of 46 on the widest spacing to a maximum of 122 on the narrowest. At age 20, square foot basal areas per acre ranged from a minimum of 174 on the widest spacing to a maximum of 210 on the narrowest spacing.

Combined, the USFS study and the MSU study produced a total of 815 yield and 467 growth observations. Total tree inside bark cubic foot volume yields per acre were determined by first deriving an equation to estimate total tree height from DBH, stand age, average height of dominants and codominants, basal area per acre, and number of trees per acre. Plot volumes were then calculated by using predicted heights and observed DBH in the total tree volume equations:

$$V = .0059 + 0.0019543(DBH)^2H \tag{1}$$

where, V is total tree cubic foot volume inside bark (ib) , H is the total tree height in feet and DBH is in inches. The total tree volume equation was derived from 298 sample trees from another study of the yield of old-field loblolly pine plantation&'.

The total tree height prediction equation developed from the data is:

$$\ln(H) = \ln(C_0) + C_1/DBH \tag{2}$$

where

$$C_0 = \bar{H}[1 + a_1 EXP[a_2(Q/\bar{H})^{a_3}]],$$

$$C_1 = [\ln(\bar{\bar{H}}) - \ln(C_0)]Q,$$

$$\bar{\bar{H}} = \bar{H}EXP[b_1\bar{H}^{b_2}/(b_3 + Q)^{b_4}] ,$$

H = total tree height in feet,

$\bar{H}$ = average height of dominant and codominant trees in feet,

Q = quadratic mean DBH of stand in inches,

ln = natural logarithm,

3/ The study was installed in 1959 and has been subsequently maintained by Dr. George L. Switzer . The authors deeply appreciate Dr. Switzer permitting the use of these data for the study.

4/ Now the John W. Starr Memorial Forest.

/Franklin, R. D. 1978. Predicted stand structure and yield of unthinned loblolly pine plantation in the central Gulf coastal Plain. Unpublished thesis. Mississippi State University, Department of Forestry.

EXP = base of natural logarithm, and

a_i's, b_i's = parameters to be estimated from the data.

Equation 2 was derived by fitting the logarithm of height reciprocal of DBH regression model, $\ln(H) = \ln(C_0) + C_1/DBH$, to the (DBH, H) pairs of each plot. Nonlinear regression equations were then found to predict CO and $\bar{\bar{H}} = C_0 EXP(C_1/Q)$ from the predictor variables Q and i-i.

$$CO = \bar{H}[1 + a_1 EXP[a_2(Q/\bar{H})^{a_3}]], \qquad (3)$$

$$\bar{\bar{H}} = \bar{H} EXP[b_1 \bar{H}^{b_2}/(b_3 + Q)^{b_4}] \qquad (4)$$

An equation for predicting Cl was obtained by equating equation 4 to $C_0 EXP(C_1/Q)$ and solving for Cl.

$$C_1 = [\ln(\bar{\bar{H}}) - \ln(C_0)]Q. \qquad (5)$$

It should be noted that $\bar{\bar{H}}$ is the predicted height of a tree having a diameter equal to the quadratic mean diameter, Q. It should also be noted that $\bar{H}$ is defined here as the average height of the trees of maximum DBH. Conversion from the usual definition of dominant height (H_d) can be made using:

$$\bar{H} = 1.11238 H_d e^{-.000902 H_d} \qquad (6)$$

The estimated coefficients for the height defining function were: al = 0.30145, a_2 = -17.24529; a_3 = 2.20476; b_1 = -0.099223, b_2 = 1.28403, b_3 = 1.62, and b_4 = 2.36952. The regressions were based on 623 pairs and the standard errors of prediction for C_0 and $\bar{\bar{H}}$ were 3.8, and 1.09 feet, respectively.

The site index guide curve prepared from the 623 stand age (A), $\bar{H}$ pairs is

$$A\ln(\bar{H}) = -10.290 + 4.750A \qquad (7)$$

The standard error of prediction was 3.60. The dependent variable of the equation is written as age times the logarithm of dominant height to indicate the equation was weighted by age.

METHODS

The method employed in the past for modeling unthinned stand diameter distributions has been to (1) obtain sufficient temporary plot data balanced by age, site and density classes, (2) assume a family of statistical probability distributions, (3) estimate the parameters of the assumed probability model for each plot using maximum likelihood, moment, or least square procedures, and (4) apply regression analysis to calculate prediction equations for the parameters using age, site index (dominant height), and number of surviving trees, along with an equation to predict surviving trees. A simple sys tern results, in which expected frequencies, volumes, and multiple products by diameter class are readily obtainable.

Conceptually, a similar procedure could be employed for estimating diameter distributions of thinned stands from permanent plot data. Exclusive use of the modeling method would most likely require separate parameter estimating equations for differing types of thinnings at differing levels, as well as a complex of equations to grow stands following thinning. Further, maintenance of logic between before, after, and future stand tables would at best be difficult, if not impossible,

Another approach recently proposed by Matney and Sullivan (1982) and Hynick and Moser (1982), leads to a highly flexible framework to model the distribution of thinned and unthinned stands. In the method, part of the distribution parameters are estimated by regression procedures and others are recovered so the resulting distribution integrates to stand level estimates such as basal area, volume, and arithmetic mean diameter. The procedure thus, primarily requires equations for estimating stand level variables for thinned and unthinned stands, plus procedures for recovering distribution parameters. Because of this, it is possible, through a unified set of procedures, to simulate a wide variety of different types and levels of thinning.

The system described herein for thinned and unthinned loblolly pine plantations is based on recovering the parameters of the three parameter Weibull distributions (equation 12) and truncated three parameter Weibull distributions to intergrate to estimated basal area per acre and total cubic foot volume (ib) per acre. The location parameter (a) and truncation parameters of the Weibull distributions are determined by regression procedures and characteristics of a given thinning method. The scale (b) and shape (c) parameter are obtained by the *recovery* constraints. Although the Weibull distribution is assumed here, the method extends readily to other distribution forms. The Weibull distribution was chosen because of its demonstrated flexibility for describing unthinned stand diameter distributions (Bailey and Dell 1973; and Schreuder *et.* al. 1979) and its potential use as a framework for modeling thinned stands.

We will first describe the stand level equations prepared from the data for estimating per acre values of surviving trees, total tree cubic foot volume (ib), and basal area. An overview of procedures for applying the recovery method to simulate diameter distributions of thinned stands will then be given. The exact solution methods used to recover the parameters cannot be explained with any details here because of space limitations. These details are to be in an unpublished report that should be available for distribution in January, 1983. The conversational FORTRAN program from these results also contains descriptions of solution techniques. Machine readable copies of the program can be obtained from the authors on request.

Stand Level Equations

Mortality

The equation that provided the most logical projection of number of trees dying per acre is:

$$Y = 0.0005923(A_1 - A_0)^{1.1973}(N_0/B_0)^{1.884}\bar{H}_0^{1.1185}\,EXP(0.01588B_0 + 0.058861B_0/A_0 - 4.4390/A_0) \quad (8)$$

$$N = 467,\ R^2 = NA,\ Sy.x = 23.49.$$

where

- $Y = N_0 - N_1$ = number of trees dying per a&e in time interval $A_1 - A_0$,
- N_0 = initial number of trees per acre,
- N_1 = projected numbers of trees per acre = $N_0 - Y$,
- B_0 = initial basal area per acre in square feet,
- A_0 = initial age,
- A_1 = projection age, and
- $\bar{H}_0$ = average height of dominant and codominant trees in feet at A_0.

The N, R^2, and $Sy.x$ under the above equation denote the number of observations, coefficient of determination when applicable, and the standard error of prediction, respectively. This convention will be followed throughout the remainder of the paper.

Other equations fitted to the data accounted for more of the variation in N_1, but were more complex and did not behave as well as equation 8 within and outside the range of the data.

Basal Area

On the high density unthinned plots, stand basal areas peaked between the ages of 15 and 20 and thereafter declined. Attempts to find a single equation that would adequately approximate this observed trend did not produce an equation that was considered sufficiently precise. An alternative approach was thus sought. The method that proved to yield the best projection of basal area was to determine an equation for projecting the mean basal area per tree and multiply by projected number of trees per acre to calculate projected basal area. The regression equation calculated for this purpose is:

$$\bar{B}_1 = \bar{B}_0 + (A_1 - A_0)W$$

$$W = 6.5534\bar{B}_0^{1.1851}\bar{H}^{0.8868}A_0^{-1.4198}EXP(-0.37363\,B_0^{0.37649} - 2.1124\bar{B}_0^{0.33009}) \quad (9)$$

$$N = 467,\ R^2 = NA,\ Sy.x = 0.005.$$

An estimate of initial mean basal area per tree for stands not having been prwiously thinned can be obtained using the equation:

$$\bar{B} = 0.46098\bar{N}^{0.34442}EXP(-43.9103\bar{H}^{-1.25501}) \quad (10)$$

$$N = 252,\ R^2 = 0.92,\ sy.x = 0.010.$$

The bar is used to denote the means of the respective quantities.

Observed mean tree basal area should be used for stands that have been previously thinned, since the relationship between B and N and $\bar{H}$ are considerably altered from that expected for an unthinned stand.

Volume

The following equation was selected as the best among the numerous equations evaluated for estimating total tree inside bark cubic foot volume per acre.

$$V = N[0.0059 + 0.001977Q^{1.99381}C_0^{1.00006}EXP(0.95616C_1/Q - 0.00178C_0/A)] \quad (11)$$

$$N = 815,\ R^2 = NA,\ Sy.x = 1.01.$$

where

- V = total tree cubic foot volume (ib) per acre,
- N = number of trees per acre,
- C_0 = the intercept coefficient of the height - DBH curve (equation 2),
- C_1 = The slope coefficient of the height - DBH curve (equation 2), and
- A = stand age.

The term .0059 in the above equation is the intercept term from the true volume equation (equation 1) and was hence not estimated when the equation was fitted to the data.

Diameter Distributions

Initial Evaluation

Evaluation of the change in diameter distribution due to time or method of thinning requires the determination of an initial diameter distribution. This section describes a technique for calculating three parameter Weibull distributions so that the generated distribution integrates to predicted or known values of cubic foot volume and square feet of basal area per acre. In subsequent sections procedures are given for projecting diameter distributions and simulating row and selection thinnings.

The three Weibull distributions as applied to diameter distribution data is:

$$f(x) = cb^{-1}[(x - a)/b]^{c-1} e^{-[(x - a)/b]^c}, \quad a \leq x < \infty$$

$$= 0, \quad \text{elsewhere}, \quad (12)$$

where, a, b, and c > 0 are parameters, e is the base of the natural logarithm, and X is a random variable representing DBH.

When the distribution parameters (a, b, and c) are known for a stand having N^* trees per acre, the stand's basal area (B^*) per acre can be calculated as:

$$B^* = E[KN^*(X^2)] = KN^*cb^{-1}\int_a^\infty [x]^2[(x - a)/b]^{c-1} e^{-[(x - a)/b]^c}dx = (K)N^*[a^2 + 2ab\Gamma(1 + 1/c) + b^2\Gamma(1 + 2/c)]. \quad (13)$$

E(X) denotes the statistical expectation of the random variable X, and Γ denotes the gamma function. The value of K is $\pi/576$ if B^* is expressed in square feet per acre. Further, if the functional relation between individual tree volume and DBH is known, total volume (ib) per acre can be estimated as:

$$V^* = E[N^*V^*(X)] = N^*cb^{-1}\int_a^\infty V^*(x)[(x - a)/b]^{c-1} e^{-[(x - a)/b]^c}dx \quad (14)$$

where $V^*(X)$ is a function for computing individual tree volume for a given DBH of X.

Now, if for a particular stand, V^*, B^*, N^*, and $V^*(x)$ are replaced by their observed or predicted values, equations 13 and 14 are readily solved for the b and c parameters of the generating Weibull distribution given the "a" parameter. The estimates of V^*, B^*, and N^* for the stands in this study can be obtained by substituting the height prediction equation derived (equation 2) for H in the assumed volume equation. That is:

$$V^*(x) = \alpha + \beta x^2 C_0 EXP(C_1/x) \quad (15)$$

where C_0 and C_1 are estimated by equations 2 and 5 respectively, and a and β are the intercept and slope coefficients of the assumed volume equation respectively.

To determine a suitable means of fixing the "a" parameter, the values of "a" that maximized the likelihood function under the basal area and volume constraints were found for each stand condition. Regression analysis of these "best" estimates of "a" indicated that a good procedure for fixing the "a" parameter is to set it equal to one-half the minimum stand diameter.

In stands that have not been thinned the minimum stand diameter can be predicted using the equations:

$$DMAX = Q(2.1285 - 0.355554 - 3.154Q/\bar{H}) \quad (16)$$

$N = 623$, $R^2 = 0.95$, $Sy.x = 0.64$

$$DMIN = DMAX - Q(1.3512 - 0.8121Q - 0.9340Q/\bar{H} + 0.0988\bar{H}/A) \quad (17)$$

$N = 623$, $R^2 = 0.90$, $sy.x = 0.75$.

where

DMIN = minimum stand DBH in inches, and

DMAX = maximum stand DBH in inches.

The observed minimum stand diameter should be used for stands that have been previously thinned. Thinning a stand disturbs the natural development of the stand and hence makes the prediction of minimum stand diameter for a given stand condition very suspect.

The degree of correspondence between the actual and predicted diameter distributions for a stand that has a Weibull distribution will depend on the closeness of the estimates of V^*, N^*, B^*, and $V^*(X)$ to their true values. To assess the maximum potential of the approach for describing the diameter distributions in this study, χ^2 goodness of fit tests were performed using stand tables calculated from observed V, N, B, and V(X)[6/]. These tests resulted in rejection of the hypothesis that diameter distribution is from a Weibull distribution in 10 of the 815 cases at the 0.01 level. Since the 10 rejections were close to the theoretical number of six expected rejections, it was concluded that the Weibull probability distribution would provide adequate approximations of the diameter distributions observed in this study.

Thinned

A knowledge of the effect of thinning method on the distribution of diameter, at the time of thinning and at subsequent points in time is necessary. The distribution following thinning is determined by the type and level of thinning. Distribution parameters of the thinned stand that are specified by the nature of the thinning are first ascertained. Diameter distribution recovery is then applied, if necessary, to obtain any remaining parameters from calculated residual stand basal area, number of trees, and/or volume.

Once the parameters of the thinned stands distribution have been determined, along with the stand's basal area and number of trees, the method given in the next section for obtaining a projected stand can be applied to estimate the diameter distribution of the stand at future points in time. Comparison of these estimates with those for the unthinned stand at the same point in time, allows for the evaluation of the benefit of the level and type of thinning.

The details for simulating several types of thinnings are given in the remainder of this section. Without loss of generality it will be assumed that the distribution prior to thinning is a three parameter Weibull. Distributions that have been truncated or partioned by previous thinning can be handled by minor modification (change of integration limits).

In determining the parameters of the distribution of the residual stand, it is necessary to restrict the solution space so that the recovered distribution for the residual stand does not have diameter classes with more trees than the unthinned stand. This requirement reduces to the mathematical constraint:

$$N_0 f_0(x) \geq N_1 f_1(x) \qquad (18)$$

for all x having positive probability In the unthinned stand, where N_0 and N_1 are the number of trees per unit area before and after thinning, respectively; and f_0 and f_1 are the stand's diameter distributions before and after thinning, respectively.

Row thinnings are the easiest to simulate. The expected percentage of basal area, number of trees, and volume removed is equal to the percentage of rows removed. Hence, the Weibull parameters of the thinned stand are equal to Weibull parameters of the unthinned stand. Constraint 18 is consequently satisfied without checking.

Classical thinnings from below are characterized by a progressive reduction in the proportion of trees removed in successive diameter classes. In effect the results of this are an increase in basal area and volume per tree. The corresponding effect on the residual stand diameter distribution is to shift the modal DBH class to the right and compress the distribution in relation to the initial stand distribution.

Many solutions for the Weibull parameters of the residual stand (a_1, b_1, c_1) under the recovery constraint defined by equations 13 and 14 and the logical constraint defined by equation 18 exist. Unique solutions for b_1 and c_1, however, exist for each given a_1 in the range of solutions of a_1 satisfying the recovery and logical constraints. Maximum likelihood estimates for a_1 under the defined constraints for stand's thinning from below resulted in the following equation for estimating a_1:

$$a_1 = a' + .0025(a'' - a')P_q \qquad (19)$$

where a' is the lower solution bound for a_1, a'' is the upper solution bound for a_1, and P_q is the percentage increase in the root quadratic mean diameter produced by the thinning. The parameters b_1 and c_1 are the values that satisfy the recovery constraints given a_1.

In order to characterize the selective thinnings of this type, a regression equation was developed to predict the number of residual trees from initial basal area and number of trees, and residual basal area.

[6/] The χ^2 test is not valid unless maximum likelihood estimates of distributions are used. However, comparison of maximum likelihood estimates and the moment estimators calculated from equation 10 and 11 showed they were nearly the same. Here the χ^2 should be indicative of the results that would have been realized had the maximum likelihood estimates been used. The mean difference between the maximum likelihood and the moment estimates for b and c were 0.001 and 0.05, respectively. The means of the absolute differences for b and c were 0.002 and 0.01, respectively.

$$N_1 = N_0 [1 - (1 - B_1/B_0)^{0.95958}]^{0.819344} \tag{20}$$

$N = 200$, $R^2 = 0.95$, $Sy.x = 10.2$.

where

B_0 = basal area in the initial stand,

N_0 = number of trees in the initial stand,

N_1 = number of trees in the residual stand, and,

B_1 = basal area in the residual stand.

The equation is useful for solving for the average number of trees to leave to obtain a specified residual basal area or the average amount of basal area to leave (B_1) for thinning to a specified number of residual trees. For the case of thinning to a specified residual basal area (B_1), the number of trees to leave is given directly by equation 19. The determination of the basal area to leave in the residual stand when it is thinned to a specified number of trees (N_1) is obtained by solving equation 20 for B_1.

$$B_1 = B_0[1 - (1 - N_1/N_0)^{1.2205}]^{1.0421} \tag{21}$$

Severe thinning from below results in the removal of all trees below some diameter with decreasing removals by class above the diameter. Simulating this effect requires the use of a truncated Weibull distribution wlth truncation parameter equal to the threshold diameter. Specifically, the initial stand's basal area, number of trees, and volume are reduced by the basal area (BR), number of trees (N_R), and volume (VR) removed below the truncation parameter (a_t). The truncated distribution is then formed, and the procedures described previously for the classical selection are then applied to approximate the thinning above the truncation parameter.

N_R, B_R, and V_R are defined by the relations:

$$N_R = N_0 \int_0^{a_t} f_0(x)\,dx = N_0 F_0(a_t) \tag{22}$$

$$B_R = \pi N_0 [\int_0^{a_t} x^2 f_0(x)\,dx]/576 \tag{23}$$

$$V_R = N_0 [\alpha + \beta \int_a^{a_t} x^2 H(x) f_0(x)\,dx] \tag{24}$$

The numbers of trees, basal area, and volume remaining above the a_t are thus $N = N_0 - N_R$, $B = B_0 - B_R$ and $V = V_0 - V_R$, respectively. The distribution of N, B, and V is then the truncated Weibull distribution.

$$f(x) = f_0(x)/[1 - F_0(a_t)] \quad , a_t \leq x < \infty$$
$$= 0 \quad , \text{elsewhere} \tag{25}$$

with cumulative distribution function.

$$F(x) = 0 \quad , a \leq x < a_t$$
$$F(x) = F_0(X)/[1 - F_0(a_t)] \quad , a_t \leq x < \infty \tag{26}$$

Denoting the number of trees, basal area and volume by N_1, B_1, and V_1, respectively, remaining after thinning above the truncation diameter, the recovery contraints become:

$$B_1 = \pi N_1 [\int_{a_t}^{\infty} x^2 f_1(x)\,dx]/576 \tag{27}$$

$$V_1 = N_1 [\alpha + \beta \int_{a_t}^{\infty} x^2 H(x) f_1(x)\,dx] \tag{28}$$

$$Nf(x) \geq N_1 f_1(x) \quad , a_t \leq x < \infty \tag{29}$$

where $f_1(x)$ denotes the final residual stand diameter distribution.

While the number of cases of thinning resulting in truncated residual stands, were insufficient to develop a projection equation for the a, experience with simulating the case indicates reasonable results can be obtained using equation 19. The truncation parameter is assumed to be known.

Operational thinnings from below often do not remove any trees below some minimum merchantability diameter. In this case, the initial distribution can be considered to be the weighted sum of two distributions. The distribution $f_b(x)$ of trees below the minimum diameter (a_t) and the distribution $f_a(x)$ of trees above the minimum diameter.

$$f_0(x) = [N_b f_b(x) + N_a f_a(x)]/N_0 \tag{30}$$

where

$N_a = N_0 F_0(a_t)$ is the number of trees below the minimum merchantable DBH.

$N_b = N_0[1 - F_0(a_t)]$ = the number of trees above the minimum merchantable DBH, and

$f_b(x) = f_0(x)/F_0(a_t)$

$$f_a(x) = f_0(x)/[1 - F_0(a_t)], \text{ and}$$

$$N_0 = N_a + N_b$$

The distribution $f_b(x)$ is a right truncated Weibull, and $f_a(x)$ is a left truncated Weibull. Hence, by convention $f_b(x) = 0$ for $x \geq a_t$ and $f_a(x) = 0$ for $x \leq a_t$.

Treating $f_a(x)$ as a separate distribution, the distribution of the resdual stand above the diameter a_t can be obtained from the constraint.

$$B_1^a = \pi N_1^a [\int_{a_t}^{\infty} x^2 f_a^1(x)dx]/576 \qquad (31)$$

$$V_1^a = N_1^a [\alpha + \beta\int_{a_t}^{\infty} x^2 H(x) f_a^1(x)dx] \qquad (32)$$

$$N_a f_a(x) \geq N_a^1 f_a^1(x) \qquad , a_t \leq x < \infty \qquad (33)$$

The distribution following thinning is thus:

$$f_1(x) = [N_b f_b(x) + N_a^1 f_a^1(x)]/N_1 \qquad (34)$$

where $N_1 = N_b + N_a^1$. The residual stand has a basal area of $B_0^b + B_a^1$ and volume of $V_0^b + V_1^a$ where

$$B_0^b = \pi N_b [\int_{a_t}^{\infty} x^2 f_b(x) dx]/576 \qquad (35)$$

$$V_0^b = N_b [\alpha + \beta\int_{a_t}^{\infty} x^2 H(x) f_b(x)dx] \qquad (36)$$

Operational thinnings from below which do not remove trees below some diameter but either cut to some threshold diameter above the diameter or are severe enough to remove all trees to some DBH results in a residual stand with a hole in its diameter distribution. Before thinning the stand's distribution can be partioned into three pieces: (1) the distribution $f_b(x)$ by N_b trees below the minimum merchantable diameter $[(DBH(a_t^b)]$, (2) the distribution $f_m(x)$ of trees between a_t^b and another $[DBH(a_t^a)]$, $a_t^b \leq a_t^a$ that will be totally removed in the thinning, and (3) the distribution $f_a(x)$ of N_a trees above a_t^b. That is,

$$f_0(x) = [N_b f_b(x) + N_m f_m(x) + N_a f_a(x)]/N_0 \qquad (37)$$

The function $f_b(x)$ is a right truncated Weibull defined by

$$f_b(x) = f_0(x)/F_0(a_t^b) \qquad , a \leq x \leq a_t^b$$
$$= 0 \qquad , \text{elsewhere} \qquad (38)$$

$f_m(x)$ is a left and right truncated Weibull defined by

$$f_m(x) = f_0(x)/[F_0(a_t^a) - F_0(a_t^b)], \qquad a_t^b < x \leq a_t^a$$
$$= 0 \qquad , \text{elsewhere} \qquad (39)$$

and $f_a(x)$ is a left truncated Weibull defined by

$$f_a(x) = f_0(x)/[1 - F_0(a_t^a)] \qquad , a_t^a < x < \infty$$
$$= 0 \qquad , \text{elsewhere} \qquad (40)$$

Denoting the number of trees, basal area and volume remaining after thinning of the distribution $f_a(x)$ by N_a^1, B_a^1, and V_a^1, respectively, and the residual distribution by $f_a^1(x)$, the distribution of the residual stand is

$$f_1(x) = [N_b f_b(x) + N_a^1 f_a^1(x)]/N_1 \qquad (41)$$

where $N_1 = N_b + N_a^1$. The basal area and volume of the residual stand is $B_1 = B_0^b + B_1^a$ and $V_1 = V_0^b + V_1^a$.

Combination row and selective thinnings are readily simulated by first applying the row thinning and then the selective thinning.

Projected

After calculating an initial diameter distribution, future distributions are needed at specified points in time. Equations 6, 7, and 8 provide a means of estimating surviving trees per acre, square feet of basal area, and total cubic foot volume *per acre,* respectively. Equation 2 defines the height--DBH curve for projected stands. Projection intervals of 5 or less years should be used since plot remeasurements were mostly made on intervals less than 5 years.

In determining future diameter distributions that are compatible with projected volume and basal area, it is desirable to use the DBH projection equation.

$$X_1 = a_0 + b_0[W_0 + W_1[(X_0 - a_0)/b_0]^{W_2}] \qquad (42)$$

where

X_1 = DBH at time AL of a tree of DBH X_0 at time A_0,

X_0 = initial DBH,

a_0, b_0, c_0 = parameters of the Weibull distribution at time A_0, and

W_0, W_1, W_2 = coefficients to be determined so that the distribution of the projected stand is compatible in basal area and volume.

The DBH projection equation can be interpreted as giving the amount that a tree of given diameter will shift in time. This shift can be due to either tree growth or tree death. Bailey (1980) discusses the diameter growth equation along with others and discusses their interpretation. Matney, Dell, and Switzer in an unpublished report, provide a method which under certain assumptions yields unbiased estimates of average diameter growth.

To explain further, suppose W_0, W_1, and W_2 have been determined for a projection interval as outlined above. The distribution of the projected stand can be shown to be Weibully distributed with "a" parameter, of $a_1 = a_0 + b_0W_0$, "b" parameter, of $b_1 = W_1b_0$, and "c" parameter, of $c_1 = c_0/W_2$ (Bailey 1980). That is the distribution of X_1 is Weibully distributed. Left and right truncated Weibulls are also regenerated by the transformation. A left truncated Weibull has "a", "b", and "c" parameters as given above and a left truncation parameter of

$$a_L^1 = a_0 + b_0[W_0 + W_1[(a_L^0 - a_0)/b_0]^{W_2}]. \qquad (43)$$

Similarly a right truncated distribution has a right truncation parameter of

$$a_R^1 = a_0 + b_0[W_0 + W_1[(a_R^0 - a_0)/b_0]^{W_2}]. \qquad (44)$$

Determinations of W_0 for each of the 467 growth periods that maximized the likelihood functions of the projected stand under the parameter recovery constraints were made to find a means of predicting W_0. That is, the values of W_0 were found so that when W_1 and W_2 were calculated to satisfy the recovery constraints the constrained likelihood function was maximized. Regression analysis of W_0 on initial stand condition and changes in initial stand conditions resulted in the equation,

$$W_0 = 0.25(Q_1 - Q_0)/b_0 \qquad (45)$$

where

Q_0 = initial stand root quadratic mean diameter, and

Q_1 = projected stand root quadratic mean diameter.

The prediction equation for W_0 above applies only to the case where the distribution following thinning is a three parameter Weibull. Application of the result to the more complex simulation cases produce reasonable results.

CONCLUSION

Diameter distribution recwery techniques are a highly flexible tool for simulating distributions of thinned stands in time. The power of the method permits simulation of observable conditions outside the range of available data. In the development of our computer model for thinned loblolly pine plantations, the user is permitted to simulate types of thinnings that are far outside the data range. Continuous experimentation with the model has however always indicated that the results obtained are reasonable for these cases. Verification against real data however is badly needed for cases simulated which are outside the data base.

Extensive comparison back against the conditions represented in the data base demonstrate close agreement between observed and predicted. As might be expected agreement is not as close as when observed values of N*, V*, B*, and V*(X) are used to calculate stand tables. Even so, for practical purposes the predicted stand tables were in correspondence with the observed.

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A SEGMENTED DIAMETER DISTRIBUTION METHOD FOR MODELING THINNED STAND&

Quang V. Cao[2]

Abstract .--A flexible method to approximate diameter distributions in forest stands was developed. Functions in the form of a modified Weibull cumulative distribution function (cdf) were joined together to form a segmented cdf, which was defined by five percentile points (the minimum, median, and maximum diameters, and the 25th and 75th percentiles). Further, a method for modeling growth and yield of thinned plantations was developed. The segmented cdf, employed to characterize stand diameter distributions, was searched for to insure that the resulting total basal area and average dbh estimates were identical to those predicted from stand variables using regression techniques. Stand and stock tables can be generated for present and/or future stands.

INTRODUCTION

Yield models based on diameter distributions have been used on unthinned plantations. The probability density function5 (pdf's) employed in these models vary from the beta pdf (Bennett and Clutter 1968) to the Weibull function (Smalley and Bailey 1974). Growth and yield models on thinned plantations have been recently developed using the Weibull pdf (Bailey et al. 1981, Matney and Sullivan 1982, Cao et al. 1982).

In some cases in thinned stands, the empirical diameter distributions can be irregular, and unimodal distributions (e.g. beta or Weibull pdf) may not be adequate to describe these data. In this study a more flexible approach was developed in which functions in the form of a modified Weibull cumulative distribution function (cdf) were joined together to form a segmented cdf. A method for modeling growth and yield of thinned plantations using the segmented cdf will be presented.

SEGMENTED CUMULATIVE DISTRIBUTION FUNCTION

Suppose X is a diameter random variable. A total of five percentile points were used to determine the cdf:

$$x_1 = \text{Dmin},\quad x_2 = \text{D.25},\quad x_3 = \text{Dmed},$$

$$x_4 = \text{D.75},\quad x_5 = \text{Dmax}.$$

where Dmin = minimum dbh,
Dmed = median dbh,
Dmax = maximum dbh,
D.25 = the 25th percentile for dbh where Pr(dbh 6 D.25) = .25,
D.75 = the 75th percentile for dbh.

The x 's are referred to as join points or percentilejpoints in this paper. The cumulative probability p_j's corresponding to the x_j's are given by:

$$p_j = Pr(X \leq x_j);\ j = 1,2,\ldots,5.$$

It follows that $p_1=0$ and $p_5=1$. A segmented cdf F(x) is defined here as

$$F(x) = \begin{cases} 0, & x \leq x_1, \\ F_1(x), & x_1\ 6\ x\ 6\ x_2, \\ F_2(x), & x_2 \leq x \leq x_3, \\ F_3(x), & x_3 \leq x \leq x_4, \\ F_4(x), & x_4 \leq x \leq x_5, \\ 1, & x_5 \leq x. \end{cases}$$

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In this study, a modified form of the Weibull cdf was used for each segment:

$$F_j(x) = e_j \left\{ 1 - d_j \exp[-((x-a_j)/b_j)^{c_j}] \right\}$$

for $x_j \leqslant x \leqslant x_{j+1}$; j = 1,2,3,4.

$F_j(x)$ has to satisfy the following conditions:

1. F(x) must be continuous at the join points (x_j's), or:

$$F_j(x_{j+1}) = F_{j+1}(x_{j+1}) = p_{j+1};\ j=1,2,3,4.$$

2. f(x), which is the derivative of F(x) with respect to x, must be continuous at the join points:

$$f_j(x_{j+1}) = f_{j+1}(x_{j+1});\quad j=1,2,3,4.$$

Condition (2) ensures that F(x) is smooth and the corresponding pdf, f(x), continuous at the join points. Details of the procedure for computing the coefficients for each segment were described by Cao (1981).

When $d_j = e_j = 1$, F_j is a segment of a Weibull cdf. The parameters of the segmented cdf are actually the five percentile points since a_j, b_j, c_j, d_j, and e_j can be computed from the x_j's and p_j's.

A MODEL FOR THINNED STANDS

A growth and yield model based on the segmented cdf was developed using data from the loblolly pine (*Pinus taeda* L.) mutual competition study in the Hill Farm Experiment Station, Homer, Louisiana.[3] Plots of the segmented distributions that approximate observed diameter distributions are shown in figure 1.

Prediction of the Present Stand

The minimum, median, maximum, and average dbh's can be predicted from stand variables (age, site quality, basal area and number of trees per acre). The remaining two percentiles (D.25 and D.75) were computed using an iterative procedure to insure that the resulting segmented cdf would produce the current stand basal area and an arithmetic mean dbh estimate identical to that predicted from the regression equation. Thus D.25 and D.75 were solutions of the following system of two equations:

$$B = 0.005454\ N \int_{Dmin}^{Dmax} x^2 f(x)\ dx \qquad (1)$$

$$\bar{D} = \int_{Dmin}^{Dmax} x\ f(x)\ dx \qquad (2)$$

where B = stand basal area in sq.ft./acre,
$\bar{D}$ = arithmetic mean dbh in inches from regression equation,
N = number of surviving trees per acre,
f(x) = dF(x)/dx = diameter pdf.

F(x) is the segmented cdf defined by Dmin, D.25. Dmed, D.75, and Dmax.

3/ Data from this study were described by Sprinz *et al.* (1979).

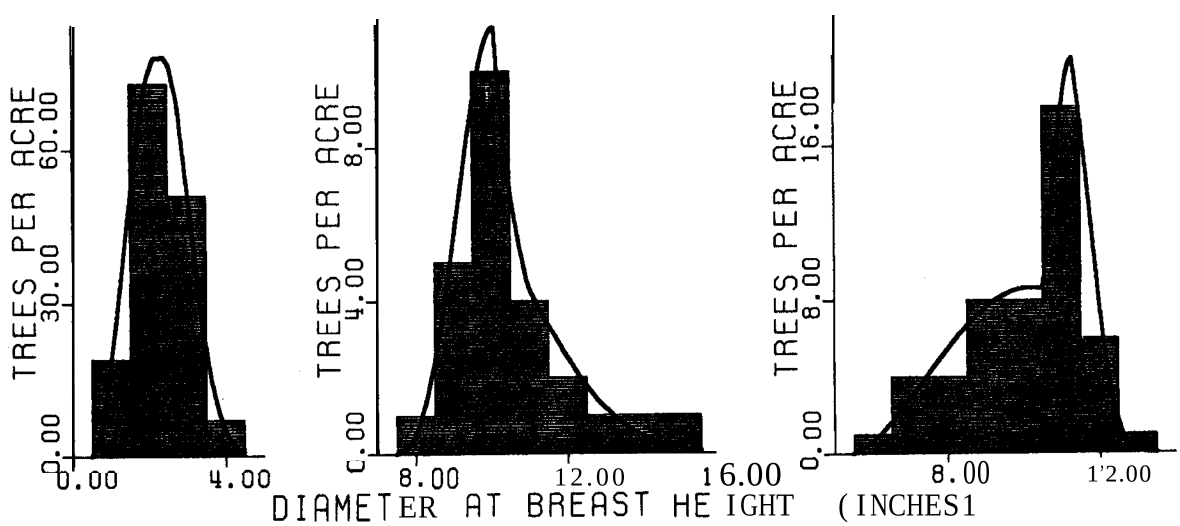

Figure 1.--Plots of the segmented distributions that approximate observed diameter distributions.

In most diameter distribution models, the sum of per-class volume and basal area over all diameter classes produces total stand volume and basal area. In a similar manner, equations (1) and (2) can be approximated by replacing the integral sign with a summation sign:

$$B = 0.005454\ N \sum_{x_i = Dmin}^{Dmax} x_i^2 f_i \quad (3)$$

$$D = \sum_{x_i = Dmin}^{Dmax} x_i f_i \quad (4)$$

where x_i = midpoint of the ith dbh class,
f_i = proportion of trees in the ith dbh class.

Equations (3, 4) are used in place of equations (1, 2) to form a system of two non-linear equations and two unknowns, namely, D.25 and D.75.

The five diameter percentiles determine a segmented cdf, and thus the number of trees per acre in each diameter class can be computed. Mean total heights for trees of a given diameter are predicted from stand variables. Volumes for each diameter class are computed using volume equations, and per acre yields are obtained by summing over diameter classes of interest.

Thinning

Since the stand table immediately before thinning is available, a variety of thinning options can be added to the model.

In row thinning, the diameter distribution is assumed to remain unchanged. Trees in all diameter classes are reduced by the same factor, which is the specified proportion of trees removed in thinning.

All trees having dbh below a certain diameter are removed in low thinning. This diameter limit can be either specified or computed from a specified residual density (basal area or number of trees per acre). The diameter distribution of a stand immediately after low thinning is truncated at the diameter limit.

Selection thinning can be simulated by assuming that the proportion of trees removed in each diameter class has a reverse J-shape when plotted against dbh, i.e., removal percent is higher for smaller trees.

In order to obtain a realistic operational removal pattern, a combination of these thinning options may be appropriate. The procedure involves application-of one thinning method after another in a sequential manner.

Prediction of the Stand in the Future

Basal area and number of trees per acre of the stand at some age in the future can be projected from initial density. Given age, site quality, and density, stand and stock tables for the future stand can be provided using procedures similar to those in predicting the present stand.

Figure 2 presents the logics used in predicting the stand and stock table of the current and future stands.

SUMMARY

A method for modeling thinned stands was developed using the segmented diameter distribution approach. Stand and stock tables of the current stand and also of the stand in the future after thinning can be generated. This system will allow forest managers to evaluate different thinning regimes.

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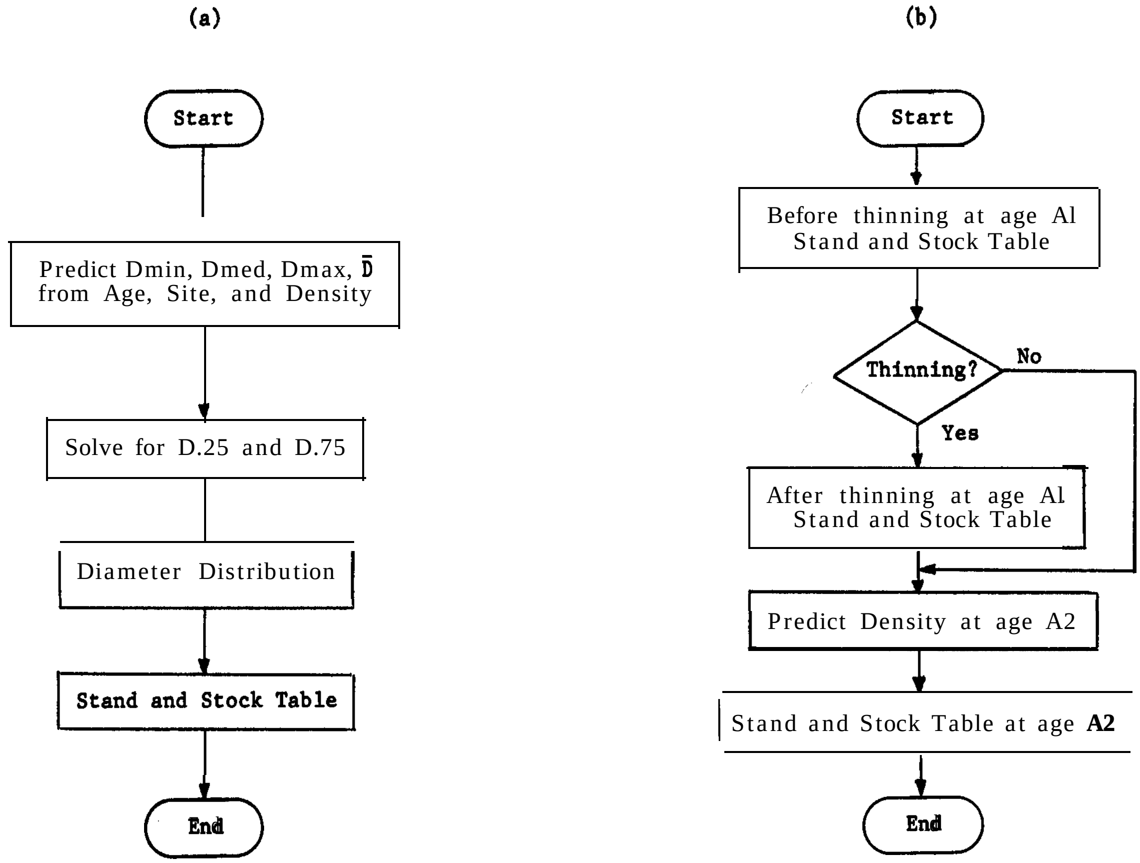

Figure 2.--Logics used in predicting the current stand (a) and the future stand (b).

DENSITY EFFECTS ON HEIGHT GROWTH AND ITS IMPLICATIONS FOR SITE INDEX PREDICTION AND GROWTH PROJECTION[1/]

F. Thomas Lloyd and Earle P. Jones, Jr.[2/]

Abstract.--Four studies (two with loblolly and two with slash pine) show an effect of number of stems per acre on mean dominant and codominant height. One slash pine study averaged a 1-foot decrease in mean height at age 30 for each 100-tree increase in planting density over the range of 200 to 1200 seedlings per acre. Ignoring this density-height effect in a growth projection model developed from the same slashpine data resulted in over-estimating growth by as much as 46 percent.

INTRODUCTION

A long held tenet of our profession is that height growth is not affected by stand densities inside the range encountered in properly managed stands. This doctrine provides the foundation for the site index (SI) model, which ignores effects of density on height and assumes that productivity can be estimated from height growth alone. The consequence is an inability to separate effects of site productivity and density on height growth.

The only way to break this circular entrapment of assumption is to make a rigorous test by applying density treatments to plots so similar in topography, soil, and past use that they can be assumed to have equal productive potential. Randomized complete block (RCB) experiments that have planting spacings as treatments would offer data to search for a density-height effect. The degree to which site productivity differences are separated from the effects of density on height growth is directly proportional to the uniformity of plots within blocks. Unfortunately, blocks in spacing studies must be quite large and so plots are not necessarily as uniform as we would like. Nevertheless, lacking better data, we examined density-height trends in four studies, two loblolly pine spacing studies, a slash pine precommercial thinning study, and a slash pine spacing study. The objective here is twofold; first, to verify or reaffirm (depending on your persuasion) the existence of a density-height effect using several independent studies, and second, to use the slash pine spacing data to measure the effect of the density-height relation on prediction accuracy for periodic volume increments from yield models that use SI as a predictor (or driving) variable.

EXAMPLES OF DENSITY-HEIGHT EFFECTS

Eighteenth-year measurements are available from an unpublished loblolly pine spacing study located on the Santee Experimental Forest, in Berkeley County, South Carolina. The study contains eight spacings consisting of 15x15, 11x11, 9x9, 7x7, 6x6, 5x5, 4x4, and 3x3 feet, replicated four times in 7-acre blocks. Mean total heights of the five tallest sample trees on each treatment plot are 56, 52, 58, 54, 53, 52, 49, and 45 feet, respectively. Although a trend of decreasing mean height with increasing planting density is apparent, we believe it is partly obscured by variation resulting from differences in soil type and drainage within blocks.

A second loblolly spacing study is on the Calhoun Experimental Forest on Piedmont soils near Union, South Carolina. It consists of four blocks, each with four spacings of 12x12, 10x10, 8x8, end 6x6 feet. Means of the five tallest sample trees from the 20-year measurements reported by Harms and Lloyd (1981) are 65, 63, 60, and 59 feet, respectively. A relationship of decreasing mean height with increasing planting density is also present in these data, and this effect is occurring over a more narrow density range than the first study.

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From an RCB-designed, slash pine precommercial thinning study, Jones (1977) reported a linear relationship (R^2=0.903) of mean dominant and codominant height (H) over present number of trees at age 23. It might be argued that such an effect is expected from the wide density range in his experiment (279 to 5802 trees per acre at age 23), but a subset of these data with numbers of trees in the range of 279 to 2126 per acre produced a slope of -0.69 feet for each 100-tree increase on density and an R^2 of 0.858. This regression predicts a 4.2 foot decrease in mean H when density at age 23 is increased from 300 to 900 trees per acre.

The fourth study is with slash pine on the Holt Walton Experimental Forest, near Cordele, Georgia, in the middle Coastal Plain. It consists of two blocks planted at spacings of 15x15, 7.5x15, 10x10, 6x12, 8x8, 5x10, 6x8, and 6x6 feet. Table 1 presents the intercepts and slopes from linear regressions of mean H over number of planted seedlings (hundreds per acre) for ages 10, 15, 20, 25, and 30. The decrease in mean H is small at age 10, but by age 30 increases to l-foot per 100-tree increase in planting density in the range of 200 to 1200 seedlings per acre.

A summary of part of the mean H data from the slash pine spacing study is given in Table 2. We assume that the observed trends in Table 2 represent effects of density on height growth and not differences in SI. This assumption of uniform site potential of plots within blocks is supported both by the closeness of the mean H values at age 10 (except for the 6x6 spacing where competition was fairly advanced by age 10) and the smoothness of the linear relations of mean H over planting density. These mean H and stand age (t) data are used with Bennett, McGee, and Clutter's (1959) old-field, plantation SI model to produce the SI-over-time data in Table 3. Stability of SI over time means the associated spacing has a height-over-time curve similar to that of the SI curve.

Table 1.--Estimates of linear regression coefficients for predicting mean dominant and codominant height from number of planted seedlings per acre.

Age (yrs)	Intercept	Slope
	Ft	Ft/100 seedlings
10	33.21	-0.2479
15	49.59	-0.5370
20	61.01	-0.8348
25	69.12	-0.9637
30	73.35	-1.0226

Table 2.--Mean dominant an codominant heights over time from slash pi e spacing study.1/

Age (yrs)	Planting spacing (ft x ft)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	Height (ft)							
10	31.8	32.6	32.8	32.2	31.4	30.6	31.6	29.8
15	47.5	48.6	47.6	45.8	46.5	44.6		42.9
20	58.8	58.6	58.5	54.6	55.2	53.2	44.8	51.2
25	67.2	65.8	65.8	62.0	61.8	60.0	62.3	57.2
30	70.6	70.2	69.6	66.5	65.8	64.2	65.4	60.4

&/Values shown are averages for two blocks.

Table 3.--Base-age-25 site index estimates made over time on plots with different planting densities.1/

Site index prediction age (yrs)	Planting spacing (ft x ft)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	Site index (ft)							
10	67.1	68.8	69.2	68.0	66.3	64.6	66.7	62.9
15	66.2	67.7	66.3	63.8	64.8	62.2	62.4	59.8
20	66.6	66.4	66.3	61.8	62.5	60.3	61.2	58.0
25	67.2	65.8	65.8	62.0	61.8	60.0	62.3	57.2
30	65.0	64.6	64.1	61.2	60.6	59.1	60.2	55.6

A/Values shown are averages for two blocks.

GROWTH PREDICTION BIAS

Occurrence of effects like those illustrated above invalidates the foundation on which the SI model rests. This means that as a classification tool SI will be either over-estimated or under-estimated, depending on whether observed density is less than or greater than that density whose corresponding height-over-time curve equals that of the SI model. On the other hand, the effect of density on SI is not a problem in fitting yield models because SI is essentially a measure of dominant stand height, and as such will always be a highly significant variable in any yield model. The resulting model will always predict well for the SI, age, and density combinations at given points in time. The problem comes when the model is used to make predictions over time.

We evaluated the time related problem by fitting a yield model to our slash pine spacing data, and then comparing actual growth with predictions from the model. The 16 (8 spacings x 2 blocks) plots were measured 16 times, at ages 10 through 22, and at 25, 28, and 30. This produced 256 observations of total cubic foot volume per acre (V), stand age (t), SI (S) and merchantable basal area per acre (B_m). They were fit using the model

$$\ln(V) = \beta_0 + \beta_1 S + \beta_2 t^{-1} + \beta_3 \ln(B_m) \qquad (1)$$

and yielded $\hat{\beta}_0 = 3.1508844$, $\hat{\beta}_1 = 0.02566564$, $\hat{\beta}_2 = -19.403421$, $\hat{\beta}_3 = 0.82870861$, and an $R^2 = 0.993$. As you would expect from such a high R^2, yield predictions checked back very closely with observed volumes; so we concluded that the model is good.

The fitted yield model was next used to predict total cubic foot growth by incrementing stand age (t) and basal area (B_m). Basal area increment comes from observed density-over-time data presented in Table 4. The above prediction process assumes SI is constant for any growth period. For this research we used the mean SI at age 10 as this constant SI value (66.7 feet at age 25). Of course, Table 3 contradicts this assumption so the above defined predicted growth was compared with actual growth obtained by using Stand age and basal area, plus the observed SI values from Table 3.

Differences in these two volume increments (Predicted-Actual) are presented in Table 5. They result from assuming SI does not change over the projection period. The bias increases with decreasing spacing from the widest spacing (15x15) because height, growth associated with this spacing most nearly matches that of Bennett, McGee, and Clutter's SI model. The trend of increasing bias with increasing length of the projection period is due to the cumulating effect over time of density on height growth. Table 6 presents these volume growth differences as percentages of actual volume growth defined in the previous paragraph.

CONCLUSIONS

Four independent studies show height growth of both loblolly and slash pine to be reduced as stand density increases inside a range considered proper forest management. Existence of this effect repudiates a foundation principle of SI, which in turn invalidates it as a determinant in studying growth and yield relations over time. Specifically, we showed that substantial bias can result in periodic growth predictions from a yield model built on data containing an effect of density on height, even when the model otherwise fits the data closely. The direction of the bias will depend on where in the density range height growth matches the SI curve. In this example it occurred at the widest spacing, but it could occur at any stocking level, depending on the properties of the two data sets used to fit the yield and SI models.

Any attempt to modify SI to handle density would be self defeating in that the purpose and primary defense of SI has been its independence from effects of density. Such an effort would also validate the arguments of those who would use volume to measure productivity of forested sites.

This along with the poor precision of the SI predictor (Lloyd and Hafley 1977, Lloyd 1981, Lloyd, Muse and Hafley 1982) suggests that we should be investigating alternative methods of using measurements of trees to establish forest site productivity.

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Table 4. Wean merchantable basal area per acre.1/

Age (yrs)	Planting spacing (ft x ft)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	Basal area (sq ft)							
10	44	70	74	82	84	82	95	61
15	71	102	108	114	128	125	137	122
20	96	121	132	131	147	143	154	147
25	111	135	140	138	150	145	153	154
30	114	137	135	132	140	133	134	144

L/Values shown are averages for two blocks.

Table 5.--The amount merchantable cubic foot volume (o.b.) is overestimated when the density-height effect is ignored.

Growth period (yrs)	Planting spacing (ft x ft)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	Volume (cu ft)							
10-15	21	-58	24	173	127	284	294	413
10-20	7	27	39	442	421	608	562	819
10-25	-51	107	110	539	600	778	552	1116
10-30	197	282	343	684	790	923	807	1373

Table 6.--Percentage by which growth is over-estimated when the density-height effect is ignored.

Growth period (yrs)	Planting spacing (ft x ft)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	- - - - - - - - - - - - - Percent - - - - - - - - - - - - - -							
10-15	2	-4	2	15	9	24	23	34
								37
10-25	-0	3	3	19	19	28	18	38
10-30	6	7	9	22	24	31	27	46

AN EMPIRICAL FUNCTION FOR PREDICTING

SURVIVAL OVER A WIDE RANGE OF DENSITIES[1/]

William R. Harms[2/]

Abstract.--A flexible sigmoid function of the form $S = 1/[1 + (H/H_c)^{\theta}]$, where S is survival expressed as the ratio of number of living trees (N) to the number of trees at stand establishment (N_i), H is mean stand height, Hc is mean height at S = 0.5, and 8 is an exponent defining the shape of the curve, was fit to a set of loblolly pine survival data covering a range of densities from 1000 to 16,000 trees per acre. The equation provided an adequate fit to the data with r^2 values from 0.76 to 0.98. The estimated parameters H_c and θ were found to be correlated to initial density. Both can be predicted satisfactorily with regressions of the form $H_c = b_0 N_i^{b_1}$, and $\theta = b_0 + b_1/N_i$.

INTRODUCTION

Reliable prediction of survival is essential to accurate prediction of growth and yield. A number of mathematical models have been used with varying degrees of success to describe the relationship between survival or mortality and selected characteristics of the stand, but a completely adequate model has yet to be developed (Burkhart et al. 1981, Somers et al. 1980). The difficulty in obtaining a satisfactory model stems from the fact that mortality is extremely variable, depending as it does on competitive ability and inherent growth rate of the species, and such external factors of site as soil moisture and nutrients. Further difficulties in modelling are encountered when attempts are made to include catastrophic mortality caused by such isolated occurrences as insects, disease, fire, and wind and ice storms,

Survival curves have a characteristic sigmoid shape over the course of stand development. The form of survival curve for a particular stand depends primarily on the number of trees established, inherent growth rate, and the site quality, Logically, the curve should be describable in terms of one or more of these variables, and in fact the published models show that initial number of trees and stand height as well as age are predictors of survival,

An empirical model is presented in this paper that closely fits survival data obtained from experimental plots of loblolly pine (*Pinus taeda* L.) grown over a wide range of densities. Preliminary results suggest that the model may be useful as a general survival function for cases where mortality is more or less regular.

THE MODEL

Sigmoid response curves are common in biological systems, and many different forms of equations have been suggested to describe various growth and development phenomena. The particular form chosen to model survival was

$$S = 1/[1 + (H/H_c)^{\theta}] \qquad (1)$$

where S is survival expressed as the ratio of number of surviving trees (N) to number of trees at stand establishment (N_i), H is mean stand height, H_c is mean stand height at S = 0.5, and θ is an exponent defining the shape of the curve. Expressions of this form are described by Thornley (1976) as threshold response curves of the switch-off type. The function varies between 1 and 0, approaches 1 for $H \ll H_c$ and falls monotonically, tending to zero for $H \gg H_c$, and passing through the value 0.5 for $H = H_c$. The higher the value of 8, the higher the value of S for $H < H_c$, the steeper the fall of the curve in the region $H = H_c$, and the smaller the value of S for $H > H_c$. There is a point of inflection at

1/ Paper presented at the Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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$$\frac{H}{H_c} = \left[\frac{\theta-1}{\theta+1}\right]^{1/\theta} \qquad (2)$$

As θ increases, the point of inflection moves closer to $H/H_c = 1$.

This equation was selected because of its simple algebraic form and because its properties appeared to fit a wide range of survival curves.

Mean stand height was selected as the predictor variable because it is an indicator of both the stage of biological development of the trees making up the stand, and the quality of the site. Height is also a measure of the age of the trees, and is somewhat sensitive to stand density.

A TEST CASE

The model was tested by fitting equation (1) to a set of survival data taken from a study of stand development in young even-aged **loblolly** pine (Harms and **Langdon** 1976). The data consisted of annual measurements of d.b.h., height, and survival from age 3 through 24 of a series of 0.1 acre density plots. Five density levels of 4 replications each were established at age 3 in a uniform stand of naturally regenerated seedlings by thinning plots back to 1000, 2000, 4000, 8000, or 16,000 trees per acre. These density levels will be referred to by number of trees present at age 3; thus 1M is an initial density of 1000 trees per acre. One plot of the 1M density was deleted from the data set because of unexplained, unnaturally high mortality in the 15th year, Mortality over all densities was quite high for the first 2 years following thinning after which it leveled off to a more expected pattern. This mortality was thought to be caused by the sudden release required to establish the treatment densities. To avoid inconsistencies in the data from this source, the number of trees present at age 6, when the plots appeared to have stabilized, was taken as the initial number (N_i) rather than the number at age 3.

Equation (1) was fitted to the data by estimating H_c and θ with a nonlinear least squares procedure. Initial values for H_c, the mean stand height at a survival of 50 percent, were estimated for each plot from scatter diagrams of the data, The starting value for θ was arbitrarily set at 2. The equation was fit separately to each plot, and then to each density with the plots pooled.

Scatter diagrams of the estimated parameters for the individual plot data show that both Ii, and θ are correlated with initial density. The relation of H_c to density is very good (fig. 1). A regression of the form

$$\text{Log}_e\, H_c = b_0 + b_1 \log_e N_i \qquad (3)$$

where H_c and N_i are defined as above, was fit to the data. Figure 1 shows the curve and its equation in exponential form. There is very little variation in H_c about the curve throughout the range of densities.

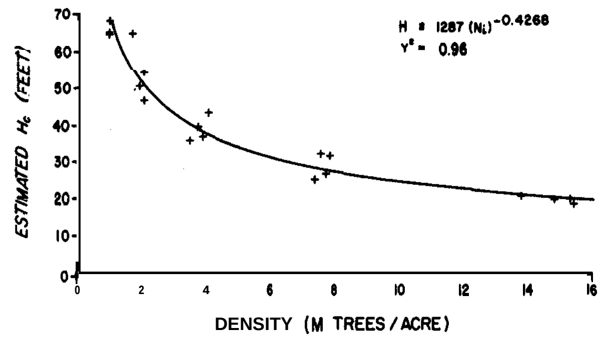

Figure 1.--Scatter diagram of estimated "H_c" in relation to initial density.

The relation between θ and initial density is much more variable, the greatest variation being at the 1M and 2M density levels (fig. 2). The variation is due to differences among these plots in the onset of mortality. High values of θ are associated with plots that were older and taller than average when mortality began. The values of θ for the denser plots in which mortality began at younger ages were much more closely grouped. A regression of the form

$$\theta = b_0 + b_1 \left[\frac{1}{N_i}\right] \qquad (4)$$

was fit to the data, with θ and N_i as defined above, Figure 2 shows the curve and its equation. The regression is significant, but fit is rather poor because of the wide variation in the 1M and 2M plots, Additional data at lower densities will be needed to establish the best form of the regression.

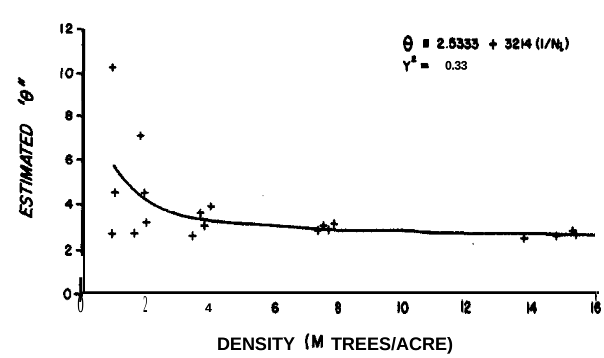

Figure 2.--Scatter diagram of estimated "θ" in relation to initial density.

Parameter estimates from the individual plots when pooled for each density are given in Table 1 together with the variation accounted for (r^2). The fit of the model was good, the r^2 increasing from 0.76 for the 1M density to 0.98 for the 16M density. The parameter values from the pooled analyses were used in the model to calculate estimated survival for each density level. The results are plotted in Figure 3 together with the actual mean survivals. The curves show that the model provides an adequate fit to the data over all densities with the possible exception of the 16M density for which early survival is underestimated. An explanation is being sought in further analyses of the data.

Table L--Parameter estimates for the survival function with the plots in each density pooled.

Density	H_c	θ	r^2
1M	65.81	4.7611	0.7618
2M	54.56	3.6826	0.8594
4M	39.46	3.2766	0.9580
8M	29.58	2.9687	0.9690
16M	20.62	2.7151	0.9851

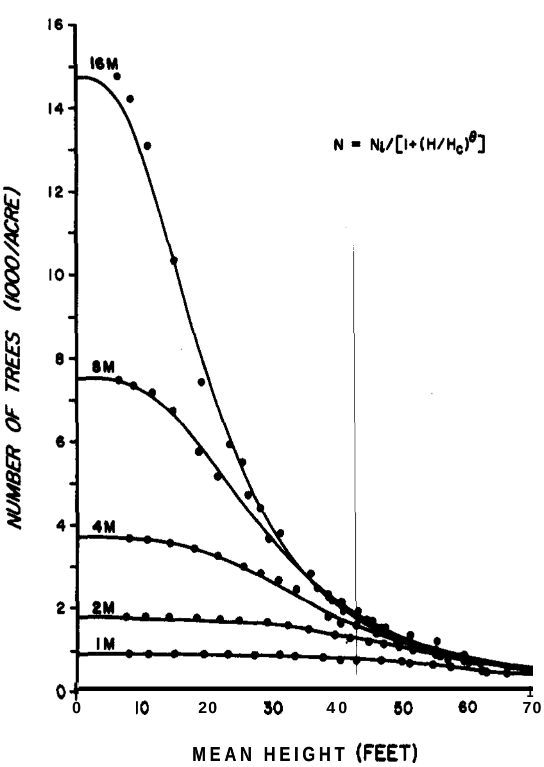

Figure 3.--Survival trends in relation to stand height for loblolly pine at five densities.

The entire data set with all 5 densities pooled also was fit, putting H_c values for each density equal to those given in Table 1. The value estimated for θ was 3.3319, the r^2 equalled 0.97. In spite of the high r^2, predicted survival was greatly underestimated at the H/H_c values above about 1.4. This result shows, as do the values of θ in Table 1, and the regression in figure 2, that a constant value for θ probably cannot be used over the range of densities spanned by these data. However, a constant θ may be satisfactory over a more restricted range of densities.

DISCUSSION

The results presented here are preliminary but they show that the model has considerable promise. It gives an excellent fit to survival data of the kind used in the test. Work is in progress to test the model on data from different sites, from plantations, and from natural stands of lower initial densities extending to older ages.

The question of how well stand height alone can account for age and differences in site quality remains to be seen. It can be assumed that H_c for a constant N_i will vary with site quality. For example, a given H_c will occur at a younger age on high sites than on low sites. What effect, if any, site has on the value of θ must be determined from actual data. If needed, a measure of site, or age, or other variable can be incorporated into the model indirectly as a variable in the regression predictors of H_c and 8, or directly by modifying the model term H/H_c so that

$$(x/x_c)^{\theta} = (x_1/x_{1c})^{\theta_1}(x_2/x_{2c})^{\theta_2}\ldots(x_n/x_{nc})^{\theta_n} \quad (5)$$

where $x_1,..x_n$ are variables such as height and site index, and $\theta_1. . .\theta_n$ are the corresponding exponents.

If mortality instead of survival must be predicted, equation (1) can be rewritten so that

$$M = \frac{(H/H_c)^{\theta}}{1+(H/H_c)^{\theta}} \quad (6)$$

where M is mortality, the ratio of number of trees died (N_d) to initial number (N_i), and H, H_c, and θ are defined above.

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STEM VOLUME PREDICTION AND CROWN CHARACTERISTICS

OF THINNED LONGLEAF PINE PLANTATION[1]/

Richard E. Lohrey[2]/

Abstract.--Tree stem volume was estimated from the combined variable, D^2H, and crown dimensions in 35- to 45-year old longleaf pine plantations that had been thinned for 15 to 25 years. The combined variable accounted for 99 percent of the variation in stem volume. Crown dimensions could not clarify the variation related to thinning treatments.

INTRODUCTION

Tree stem volume is usually estimated from tree diameter outside bark and either total or merchantable height. Several attempts were made recently to improve the accuracy of volume predictions by fitting separate functions to data for trees in different live crown ratio classes (Dell and others 1979, Feduccia andothers 1979, Baldwin and Polmer 1981). This procedure should improve volume estimates because stem form is correlated with crown size and its distribution on the stem (Larson 1963). So it is important to determine how live crown ratio and other crown characteristics are related to stem or bole volume in thinned stands. This paper reports such relationships in three thinning studies in longleaf pine plantations. Stem volume in this paper is total volume outside bark of the main stem from a 6-inch stump to the terminal bud.

METHODS

The first study, in central Louisiana, was conducted on cutover longleaf pine land typical of many areas in the West Gulf coastal plain. Native grasses dominated the site at planting because frequent wildfires controlled most hardwoods after the virgin stand was felled. Site index averaged 78 feet and ranged from 70 to 87 at base age 50.

Pines were planted at initial spacings of 4.3- by 4.3-ft., 5.2- by, 5.2-ft., 6.2- by, 6.2 ft. and 13.1- by 13.1-ft. These are equivalent to planting densities of 2,500, 1,600, 1,150 and 250 trees per acre. Three of the rates are higher than present standards. Heavy early mortality reduced the number of survivors at age 20 to that of stands with wider initial spacing and lower early mortality. At age 20, density ranged from 78 trees per acre in the widest spacing to 519 trees per acre in the narrowest one. Each spacing was repeated in four plots within each of four completely randomized blocks. This permitted future establishment of four thinning treatments at each spacing.

Thinning treatments were initiated at age 20 and repeated every 5 years to age 45. In the three close spacings, plots were thinned to residual densities of 60, 80 and 100 sq. ft. of basal area per acre. The fourth thinning left a maximum of 100 merchantable crop trees per acre at age 20 with no subsequent partial cuttings. A few submerchantable trees left at age 20 later grew into merchantable size and still survive.

Plots planted at 13.1- by 13.1-ft. spacing were not thinned because their average density was low. Stands here were similar to the crop tree thinnings in narrow initial spacings. Therefore, unthinned plots in the widest spacing and once-thinned plots in the three narrow spacings were considered as the same treatment.

The second thinning study was installed in 24- and 25-year-old longleaf pine plantations in East Texas. Both stands had been planted at 6- by, 6-ft. spacing on cutover longleaf pine land. Sample plots averaged 582 trees and 112 square feet of basal area per acre. Site index ranged from 75 to 90. Residual densities ranged from 40 to 140 square feet of basal area per acre in increments of 20 sq. ft., plus unthinned checks. Plots were inventoried and thinned at 5-year intervals to ages 39 and 40.

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The third study was in a longleaf pine stand that had been planted at 6- by 6-ft. spacing on an abandoned field in Mississippi. Sample plots were established at stand age 20. Stand density at that age averaged 537 trees and 87 square feet of basal area per acre. Residual densities assigned to the plots again ranged from 40 to 140 sq.ft. per acre plus an unthinned check treatment. Plots were inventoried and thinned at 5-year intervals to age 35.

Thinning in all three studies was from below with some, but not all, submerchantable trees being cut. Plots that had not reached their assigned density were not cut until the next scheduled thinning five years later.

The same measurement methods and procedures were used in the studies. Diameters at 4.5 feet of all trees 0.6 inch or larger were measured to 0.1 inch. Height to each 2-inch taper step was measured on sample trees and their stem volume outside bark was determined by height accumulation (Grosenbaugh 1954). Total height, height to the base of the live crown, and crown class were recorded for each sample tree. At the most recent inventories, crown diameter in two perpendicular directions was measured on sample trees from all diameter classes on each plot. Most data used in the analysis came from stands that had been thinned 3 to 5 times over a period of 15 to 25 years. The exceptions were data from unthinned checks or plots that had not reached their assigned basal area.

Data were tested by weighted multiple linear regression techniques (weight $=1/D^2H$). Separate but similar analyses were made for each of the three studies. The dependent variable was sample tree volume outside bark as determined by height accumulation. The first independent variable was always the combined variable (D^2H). Other variables tested were live crown ratio (CR), crown class (CC), average crown width (ACW), and thinning treatment (TMT). Crown ratio and average width were continuous variables; crown class and thinning treatment were discrete variables.

RESULTS

First Study

There was a strong relationship between the combined variable (D^2H) and stem total volume. This one variable alone accounted for 99 percent of the variation in stem volume (R^2 = 0.9888) and had an error mean square of 0.000406896. When thinning treatment and its product with D^2H were included in the model, the main effect of treatment was significant but the product term was not. The results indicated that the slope of the volume-D^2H regression was similar in all treatments but the intercepts were different. The interaction or product term was deleted from the model and the analysis repeated with only D^2H and treatment as independent variables. The new equation had an R2 of 0.9901, an error mean square of 0.00036424, and the effect of treatment was significant (Table 1).

When the three independent variables of crown size or distribution were added to the previous model, all were significant. They did not explain the differences in stem volume among thinning methods, however, because the variable for thinning treatment remained significant in the presence of all three crown variables (Table 2).

Second Study

In the second study the combined variable explained 99 percent of the variation in stem volume (R^2 = 0.9929) and the l-variable equation had an error mean square of 0.0002388. The effect of treatment was significant.

Live crown ratio was not significant in the equation including D^2H and three crown variables so it was deleted from the analysis in the second study. In the reduced model, one containing D^2H, crown class, and average crown width, all three independent variables were highly significant. The prediction equation had an R^2 of 0.9937 and an error mean square of 0.00021456, not much different from those of the equation that used D^2H alone. The effect of thinning treatment was significant when tested in an equation that included crown class and average crown width as independent variables (Table 3).

Third Study

The combined variable alone accounted for 99 percent of the variation in tree stem volume in the third study. Error mean square was 0.00024619. The interaction between D^2H and treatment was not significant, indicating the slope of the regression of stem volume on D^2H was similar in all treatments. The effect of treatment was small but highly significant so the regression had different intercepts among the treatments.

When all three crown variables were tested with D^2H, live crown ratio was not significant. The equation for the reduced model had an R^2 of 0.9937, an error mean square of 0.00021549, and all remaining independent variables were significant (Table 4). when thinning treatment was added to the reduced model, treatment was significant in the presence of the two remaining crown variables, but crown width was not significant after thinning treatment was included (Table 5).

Table 1.--Analysis of variance of stem volume in study number one

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	FVALUR
MODEL	4	17.43313196	4.35828299	11965.26
ERROR	477	0.17374477	0.00036424	PR > F
CORRECTED TOTAL	481	17.60687674		0.0001
R-SQUARE	C.V.	STD DEV	VOL MEAN	
0.990132	0.0574	0.01908520	33.22921162	
SOURCE	DF	TYPE I SS	F VALUE	PR > F
D^2H	1	17.41057824	47799.11	0.0001
TMT	3	0.02255373	20.64	0.0001
SOURCE	DF	TYPE IV SS	F VALUE	PR > F
D^2H	1	13.29087946	36488.86	0.0001
TMT	3	0.02255373	20.64	0.0001

Table 2.--Analysis of variance of stem volume with crown characteristics in study number one

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	9	17.45149797	1.93905533	5890.34
ERROR	472	0.15537877	0.00032919	PR > F
CORRECTED TOTAL	481	17.60687674		0.0001
SOURCE	DF	TYPE IV SS	FVALUR	PR > F
D^2H	1	1.46403957	4447.37	0.0001
LCR	1	0.00302832	9.20	0.0026
CC	3	0.01233984	12.50	0.0001
ACW	1	0.00203466	6.18	0.0133
TMT	3	0.01162126	11.77	0.0001

Table 3.--Analysis of variance of stem volume in study number twc

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	11	12.19290336	1.10844576	5313.77
ERROR	353	0.07363532	0.00020860	PR > F
CORRECTED TOTAL	364	12.26653868		0.0001

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
D^2H	1	0.92285861	4424.09	0.0001
CC	3	0.00374501	5.98	0.0006
ACW	1	0.00134683	6.46	0.0115
TMT	6	0.00339285	2.71	0.0138

Table 4.--Analysis of variance of stem volume in study number three

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	5	7.56733736	1.51346747	7023.29
ERROR	223	0.04805486	0.00021549	PR > F
CORRECTED TOTAL	228	7.61539222		0.0001

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
D^2H	1	0.81296246	3772.58	0.0001
CC	3	0.00274772	4.25	0.0062
ACW	1	0.00386865	17.95	0.0001

Table 5.--Analysis of variance of stem volume with crown characteristics and treatment in study number three

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	11	7.57111275	0.68828298	3373.06
ERROR	217	0.04427947	0.00020405	PR > F
CORRECTED TOTAL	228	7.61539222		0.0001

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
D^2H	1	0.77652035	3805.49	0.0001
CC	3	0.00233565	3.82	0.0109
ACW	1	0.00044289	2.17	0.1421
TMT	6	0.00377539	3.08	0.0064

DISCUSSION

Equations using D^2H as the only independent variable have and will serve adequately in some forestry applications. A simple function that can be easily solved on a hand-held calculator or expressed in a 1-page table is preferred. The combined variable serves admirably in those situations. It accounted for about 99 percent of the variation in tree stem volume in each of the three studies and has been equally effective elsewhere (Spurr 1952). But for some purposes, such as growth and yield studies, using a simple volume equation in all treatments may mask or hide differences in volume the studies were intended to detect and measure.

The three crown characteristics tested here gave inadequate or, at least, inconsistent results. Significant differences in stem volume among treatments remained after all other significant independent variables were included in the volume function. The same variables were not significant in any of the studies.

Stem form is influenced by the same factors or conditions that determine the size and distribution of the crown. In unthinned stands, density, age, and crown class are important. As a stand closes the lower branches die, live crown ratio decreases, and there is usually a decrease in taper of the main stem. Thus, there may be a good correlation between live crown ratio and stem taper in unthinned stands established at uniform spacing and density.

The relationship between crown dimensions and stem form is more complicated in frequently thinned stands than unthinned stands. Heavy thinning has an almost immediate effect on the amount and distribution of new wood formed on a tree stem (Larson 1963). The result is more taper brought about by increased diameter growth in the basal portion of the tree. Crown expansion begins after thinning and proceeds until competition restricts further development. The response of stem form to increased crown size lags behind the immediate effect of thinning. A series of thinnings may result in a periodic cycle in crown expansion and changes in stem taper. It is not surprising that the relationships between crown dimensions and stem volume varied among the three stands with different initial densities, site indices, ages, and number of thinnings. In long-term thinning studies, determining tree form and volume directly from measurements of the stem will be better than estimating them from crown dimensions.

CONCLUSIONS

The combined variable alone accounted for most of the variation in tree stem volume and it is the only independent variable required for many applications. Crown dimensions accounted for some of the remaining variation. In longterm thinning studies, measuring stem form and volume directly will be better than estimating them from crown dimensions.

SUMMARY

Relationships of stem volume to the combined variable D H, and crown dimensions were deter- in each of three studies. The stands in Louisiana, Texas, and Mississippi, ranged from 35 to 45 years old and had been thinned for 15 to 25 years.

The combined variable alone explained about 99 percent of the variation in stem volume. Some, but not all, of the variation that was related to thinning treatments could be accounted for by including crown dimensions as independent variables. The same crown variables were not significant in any of the studies. It was concluded that in long-term experiments stem form and volume should be measured directly rather than estimated from crown dimensions.

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A REGRESSSION-ADJUSTED APPROACH CAN ESTIMATE COMPETING BIOMASS[1/]

James H. Miller[2/]

Abstract.--A method is presented for estimating above-ground herbaceous and woody biomass on competition research plots. On a set of destructively-sampled plots, an ocular estimate of biomass by vegetative component is first made, after which vegetation is clipped, dried, and weighed. Linear regressions are then calculated for each component between estimated and actual weights and are used to adjust ocular estimates of biomass on permanent or temporary plots. In trials, R^2's ranged from 0.57 to 1.00. Training hints and calculation procedures are outlined.

INTRODUCTION

How is competition between a southern pine seedling and surrounding woody or herbaceous vegetation measured? This is a relatively new question. Forest Research has not yet explored fully relations between competition quantifiers and growth responses or other physiological state variables. To be effective, a competition index must indicate the degree of competition for sunlight, growing space, soil moisture or nutrients. This paper examines a regression approach devised to facilitate quantifying above-ground woody and herbaceous biomass in competition research. This method can be used without destructive sampling to estimate biomass on permanent small-plots, where pines are being established.

Both woody and herbaceous competitors reduce growth of southern pines. Stewart (1981) summarized competition control studies for forestry in the United States and has calculated an average increase of 65 percent in conifer volume following hardwood and shrub control. However, most past studies have not related the observed growth responses to measured changes in competing vegetation. Thus, very few relationships between levels of woody competitors and growth of crop trees are documented. Although demonstrated for other forest types, herbaceous competition has only recently been shown to decrease growth in newly-established loblolly pine (Pink taeda L.) plantations (Nelson et al 1981; Knowe et al 1982; Haywood and Melder 1982). Knowe et al (1982) reported a 9-fold increase in 2-year-old tree volume with complete vegetation control, Nelson et al (1981) stated that a definable relationship exists between pine height growth and herbaceous biomass. Carter et al (1982) found that, of the quantifiers tested, oven-dry weight of competing biomass around 5-year-old loblolly pines had the greatest linear correlation ($r = 0.70$) with plant moisture stress during drought periods.

Competition indices successfully used in other regions include plant cover (Oliver 19801, weed tree basal area (Benzie 1977), and shrub crown volume (Bentley et al 1971). Unfortunately the indices chosen to date seem to be useful only for specific types of vegetation. A unifying measure is needed for all plant growth forms to permit development of more general response relationships. I suggest that biomass is one quantifying element that may have both general, as well as, local applications. Biomass estimates are currently being employed to assess herbaceous competition on a small scale in the South (Neil et al 1982).

The factors limiting widespread use or testing of biomass as a competition index appear to relate to the clip-and-weigh method. The foremost problems are the large man-power resource required in clipping numerous plots and

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the need for destructive sampling when permanent plots are required. Thus, a method is required that minimizes plot clipping and provides biomass estimates on undisturbed plots. Development of this approach drew upon procedures for quantifying forage biomass presented by Pechanec and Pickford (1937) and Wilm et al (1944). Procedure modifications specified by Blair (1958) were evaluated and will be discussed. Essentially, biomass is visually estimated on a set of plots and then measured by clipping and weighing. A linear regression is then calculated between estimated and actual weights and is used to adjust ocular estimates made on permanent plots. This approach was developed in attempts to gain a standing-crop estimate of competition on a Piedmont cutting-unit, half of which had been sheared-windrowed and half single-roller chopped (Miller 1980).

THE BIOMASS ESTIMATION METHOD

First-Stage Sampling

The double sampling method was developed and tested on a 124 ha management unit of the Union Camp Corporation on the rolling topography typical of the extreme southern Piedmont. The operational unit, divided in half, was prepared with two different site preparation methods prior to planting with loblolly pine seedlings. Reference points were established every 20 m along baselines located along ridge tops within each treatment. Five points in each area were then randomly selected for locating sampling lines. Each year 20 temporary plots (2 x 2 m) were randomly located along sampling lines, 10 per treatment area. On these plots the biomass was both estimated and clipped. Forty permanent plots were also established in each treatment. Vegetation sampling was performed in August 1978, 1979, and 1981, the first, second, and fourth growing seasons after treatments.

Above-ground biomass is estimated by components. The components were modified from Blair and Brunett (1976) and are: (1) grasses and grass-likes, (2) composites, (3) legumes, (4) other forbs, (5) vines (non-preferred by wildlife) and (6) woody flora by species. This separation permits estimating competition amounts by groups with differing control and response characteristics, as well as wildlife forage amounts. However, contrary to forage surveys, the total standing-crop of woody vegetation is estimated, rather than the current year's growth.

To minimize the biomass estimation variance, estimates should be made by one person. The training steps outlined by Pechanec and Pickford (1937) are helpful and should be followed. The first training involves the calibration of ocular estimates. They suggest that field trials be undertaken prior to actual sampling using a weighing balance. An appropriate balance weighs accurately to 2 grams and is suitably rugged for field use. Individual stems of composites and woody seedlings/sprouts are estimated, clipped and weighed for practice. Also, clumps or small mats of grass can be taken as units by which an average-size clump or mat is estimated and weighed and the process repeated until a close estimate is achieved. A reminder-card can be constructed showing approximate weights for heights of composites and woody stems, diameters of grass clumps, lengths of vines, and single rosettes of small plants. This ocular calibration procedure, based on vegetation units, can be re-employed each morning during the early field season to lend consistency to estimates.

In the next phase of training, sample plots should be examined and a small pocket calculator used to sum the estimates of the individual units counted and sized on the plot. A key to ocular estimates of standing-crop is that all individual units or plants must be seen. Seeing each part of a trailing vine and each small forb rosette requires a thorough examination. This becomes more difficult as the amount and complexity of the vegetation increases yearly on permanent plots and influences the choice of plot size.

Biomass can be estimated as green or oven dry-weights. Difficulties with changing moisture contents during a sampling season have been reported by Hilmon (1958) and resulted in costly procedures specifying continual sampling of plant moisture and adjustments of green-weight estimates. In the current study, green-weight or oven-dry weight equations could be fitted equally well, as indicated by the R^2's in Table 1. Thus oven-dry weights were estimated directly, concuring with a similar modification by Blair (1958). Obviously, dry-matter is the main substance visualized in these ocular estimates while the day-to-day variation in moisture content is not readily perceived. This recognition suggests another training aid. Specifically, during the early field season, the estimator should check daily plot estimates on clipped-plots by weighing the clipped samples in the evening and checking his estimates on a green-weight basis, making adjustments as indicated the following day. The close correlation between green and oven-dry weights permits these green-weight checks even though oven-dry based regressions will be calculated.

Training of the clipping crew must include accurate differentiation of species into component groupings. Inconspicuous plants or new species should be tagged or communicated in some manner to the crew when the estimator is not present at clipping. Stubble heights of 2.5 cm are usually specified and all clipped material must be placed in appropriately marked paper bags for oven drying.

These steps were performed in this study. Bags with plant material were oven-dried at 75OC until no further weight-loss occurred, a procedure requiring up to a week of drying for woody stems greater than 3 cm in diameter and a minimum of 24 hr for moist herbage.

Developing the Regressions

The ocular estimates of biomass from the first sampling stage are related to the measured biomass using standard linear regression techniques. The X-values are "estimated weights" and the Y values, "actual weights." These regression equations are then used to correct all data from the "estimated-only" plots. Linear regressions through the origin as specified by Wilm et al (1944) can be used. The intercept at the origin is a logical assumption, discounting mistakes such as miscommunications between estimator and clipping crew.

The various aspects of fitting a straight line through the origin are covered most completely, but still briefly, by Snedecor and Cochran (1967) on pages 166 to 171. A test of the null hypothesis that the regression lines do, in fact, go through the origin can be performed. This test was perfomed on first-year's data from the Piedmont study. T-values are presented in Table 1. The non-significant (n.s.) t-values at the 5 percent level of probability show the null hypothesis should not be rejected, and the regression lines generally go through the origin, both the estimated vs green weight regressions and the estimated vs oven-dry weights.

The linear regressions through zero in this study were calculated using the common least-squares method of calculating an unbiased regression coefficient by $b = \Sigma XY/\Sigma X^2$. This assumes that the variance of Y is constant as X increases, which has been impossible to test so far. This is especially difficult since the X's are estimated and have the most variance, not the Y's, reversing the general case given in most statistic textbooks. Figure 1 shows the point-scatter for the fourth-year sampling and these data give little indication that the variance in Y increases greatly with an increasing X. Blair (1958) reported that the variance of Y does increase with an increasing X when sampling browse and used $b = \bar{Y}/\bar{X}$ to estimate the regression coefficient. A scatter plot of data points should be constructed to determine which method is best suited for a study. If the variance of Y increases as X increases, then $b = \bar{Y}/\bar{X}$ should should provide the best unbiased estimate of b.

Second-stage Sampling

In the second stage of sampling, biomass is ocularly estimated on the permanent plots in a manner identical to that used on the 'clipped' plots. An aid to estimating exceptionally large woody plants is to clip a nearby equal-sized plant away from the plot and weigh it. Disturbance during examinations must be minimized on permanent plots. Plot dimensions must allow the estimator to stand on the outside and parting vegetation with a stick, see all individual plants. Thus, the 2 m square used in the

Table 1. Comparison between first-year regressions using estimated weight vs actual green weight or oven-dry weight showing the coefficients of determination and the t-statistics testing the H_0 that the regression goes through the origin.

Component	Estimated Weight vs Actual Green Wt R^2	t	Estimated Weight vs Actual O.D. Wt R^2	t
Grasses & Grass-likes	.81	1.63 n.s.	.80	1.98 n.s.
Composites	.87	.22 n.s.	.82	.38 n.s.
Legumes	.99	.97 n.s.	.97	.41 n.s.
Other forbs	.97	1.23 n.s.	.94	1.30 n.s.
Vines	.97	.10 n.s.	.96	.47 n.s.
Trees & shrubs:				
Quercus marilandica	.99	.30 n.s.	.99	.31 n.s.
Liquidambar styraciflua	.92	.91 n.s.	.80	1.02 n.s.
Rubus spp.	1.00	1.11 n.s.	1.00	1.00 n.s.

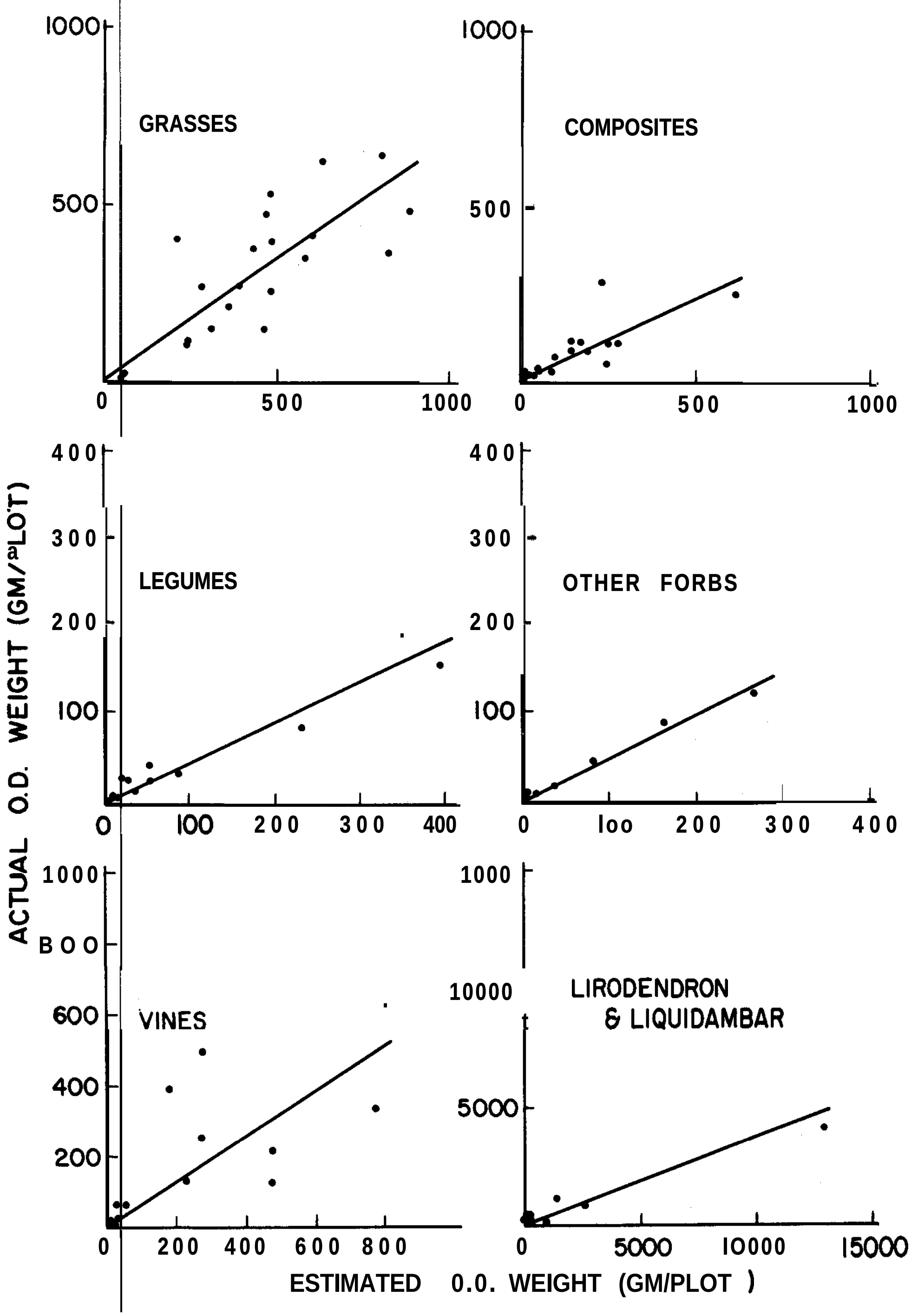

Figure 1. Data points and calculated regressions through the origins.

Piedmont example approximates the maximum dimension and larger plots would need to be rectangular. Plots of equal size must be used in the first- and second-stage sampling.

The ocular estimates of biomass on permanent plots are adjusted by multipling by the appropriate regression equations for each vegetation component and then summed.

PIEDMONT EXAMPLE

Regression coefficients calculated in the Piedmont study using $b = \Sigma XY/\Sigma X^2$ are presented in Table 2. The R^2's presented in Table 2 were computed in the normal manner using the least-squares regression calculated before forcing through the origin. Most values are close to 1.00, indicating that a linear regression explains most of the variation in Y. Woody species were grouped by similar life-form (growth habit) with 13 different regressions calculated. This many groups may not be necessary unless the differences in regression coefficients suggest that actual estimation peculiarities exist with each group. For example, Blair (1958) found it beneficial to group browse species by similar moisture contents.

An inspection of the R^2's also indicates groups that were difficult to estimate and those which became more difficult as the vegetation developed. The lower R^2's of the grasses and grass-likes certainly reflect the difficulty with estimating this group which has numerous species and various life-forms, e.g., carpets, clumps, and presence or absence of seed stocks. Estimation of composites in the fourth year was hindered by extensive woody vegetation on plots. Vines became increasingly difficult to estimate due to masking as vegetation developed and to the increasing woody and more dense nature of *Vitis* spp., the main genus.

Predicted biomass estimates and actual biomass values are shown plotted in Figure 2 for the three sampling years. This indicates the estimating capabilities for this method. The dashed lines indicating ± 20 percent of the actual biomass, shows 28, 20, and 20 percent of the first, second, and fourth year estimates, respectively, exceed these limits. Thus, the limitations of this method are apparent from this example. More of an index of competition amounts is gained, not the precise quantities. But still, the time required for estimating a plot compared to clipping a plot is 5 to 15 percent. Six to ten plots can be estimated while one is being clipped. Figure 2 shows that even though the biomass was increasing, the ability to estimate apparently improved from the first to the fourth year.

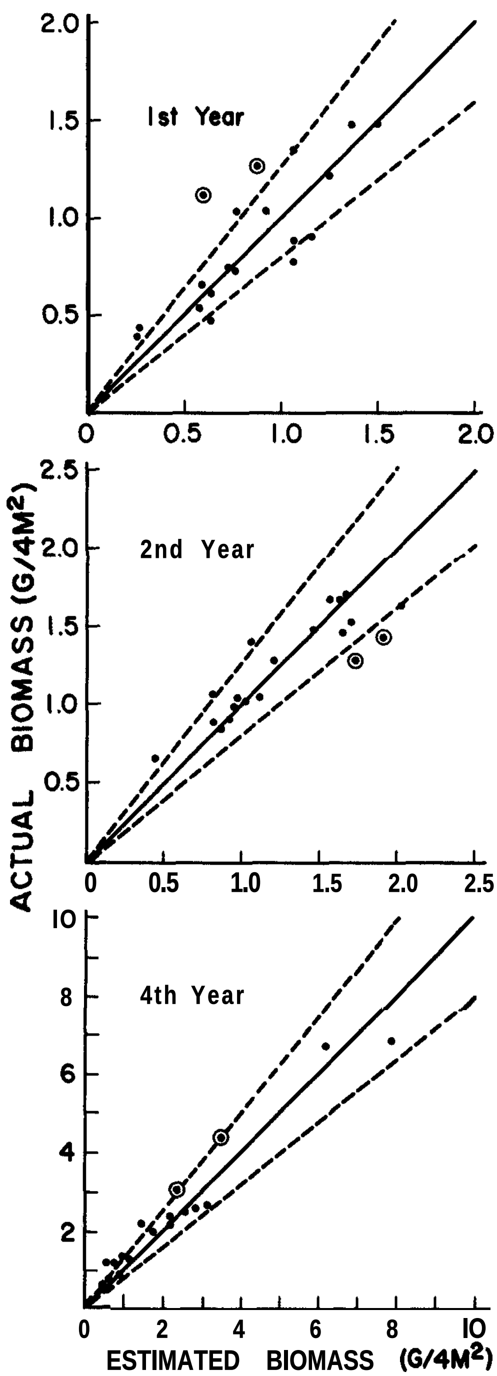

Figure 2. Estimated biomass plotted with the actual biomass. Dashed lines show ± 20 percent. Circled points indicate the first two plots estimated each field season.

Table 2. Regression coefficients and coefficients of determination by component group and year.

Component	1st Year b	1st Year R^2	2nd Year b	2nd Year R^2	4th Year b	4th Year R^2
1. Grasses and grass-likes	.49	.64	.71	.81	.69	.57
2. Composites	.45	.82	.45	.84	.47	.64
3. Legumes	.36	.94	.52	.94	.44	.94
4. Other forbs	.48	.88	.45	.89	.48	.98
5. Vines	.61	.96	.77	.87	.63	.59
6. _Rhus radicans_, _Smilax_ spp.	.56	.84	.41	.92	.57	.91
7. _Rubus_ spp., _Rosa_ spp. _Pteridium aquilinum_	.61	1.00	1.12	.98	.41	.59
8. _Vaccinium_ spp., _Viburnum_ spp.	.63	.90	.51	.99	.84	.91
9. _Calycanthus florida_ _Callicarpa americana_, _Ceanothus americanus_ _Hypericum_ spp.	.52	1.00	.53	.96	.69	.99
10. _Rhus galbra_, _R. copallina_ _Aralia spinosa_, _Hydrangea_ spp. _Sambucus canadensis_	.73	1.00	.41	.92	.58	.95
11. _Quercus_ spp.	.64	.99	.65	1.00	.33	.85
12. _Carya_ spp.	.55	.98	.91	.99	.48	.94
13. _Liquidambar styraciflua_ _Liriodendron tulipifera_	.48	.90	.49	.98	.41	.98
14. _Nyssa sylvatica_, _Ostrya virginiana_ _Diospyros virginiana_	.57	.95	.60	.96	.92	.98
15. _Prunus serotina_, _Morus alba_ _Sassafras albidum_, _Celtis occidentalis_ _Oxydendron arboreum_ _Crataegus uniflora_, _Tilia americana_	.70	.92	.61	.96	.56	.84
16. _Cornus florida_	.54	1.00	.98	.97	.71	1.00
17. _Acer rubrum_	.76	.86	.63	.98	.68	.89
18: _Pinus taeda_, _Juniperus virginiana_	.57	.95	.77	.99	.54	.91

Table 3. The percent of the predicted observations that were within plus-or-minus 10, 20, and 50 percent of the actual biomass for the 1978 and 1981 plots.

Component	1st Year			4th Year		
	10%	20%	50%	10%	20%	50%
	percent					
Grasses	20	37	73	5	20	70
Composites	21	39	71	16	47	74
Legumes	32	52	79	6	33	72
Other forbs	29	53	82	38	56	87
Vines	4	17	57	12	24	59
Rubus spp.	73	73	91	16	44	69
Liquidambar Styraciflua	21	57	93	6	25	50

An indication of the ability to estimate the different vegetation components is given in Table 3. Components can be estimated most consistently only to plus-or-minus 50 percent of the actual biomass. However, most of the values exceeding plus-or-minus 50 percent are for smaller biomass quantities. The larger quantities are closer to the actual. The summing process to obtain plot totals appears to average the over and under estimates of components to yield estimates closer to the actual (Fig. 2).

An alternate approach was examined using the fourth-year data. Instead of adjusting individually the components on plots, the adjusted plot estimates were regressed against the actual biomass values. Then the plot estimates were adjusted using this regression. This was performed to see whether a simplified method using only one biomass estimate (a sum of unadjusted components) per plot would have estimating value. Thus, a confidence interval was calculated (Neter and Wasserman 1974) for a new observation (an estimated-only plot) using both the component-adjusted and the total-adjusted approaches. For a new plot with 1000 g biomass, the component-adjusted method gave a 20 percent confidence interval of $\pm$ 674 g and the total-adjusted gave $\pm$ 912 g. For this data set, the component-adjusted method, as outlined in this paper, gave an estimate with a smaller confidence interval. Adjusting the estimates by component added to the estimating process.

With this method an estimate of the woody and herbaceous biomass surrounding a pine seedling on a permanent plot can be obtained. Most of the estimator's bias is controlled by the regression process; however, both care and consistency are required in making the ocular estimates. And often these estimates must be made in difficult and trying field situations. Experience with this approach can enhance consistency and yield estimates that are reliable within definable bounds

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A CONTINUOUS FUNCTION DESIGN FOR FERTILIZER RATE TRIALS IN YOUNG PINE PLANTATIONS[1/]

Eugene Shoulders and Allan E. Tiarks[2/]

Abstract.--A continuousvariable design is described whereby nitrogen is applied in increasing amounts to 2 m square cells in one direction and phosphorus is applied in like manner at right angles. This design made possible the testing of 121 combinations of nitrogen and phophorus rates on a 30 x 30 m area. The experimental design has potential for obtaining first approximations of fertilizer requirements cheaply and quickly. Four months after fertilization, maximum height growth occurred on loblolly pine seedlings receiving 21 kg/ha of nitrogen and 211 kg/ha of phosphorus.

INTRODUCTION

Large areas of uniform soil are required for conventional field plot experiments to establish the best rates of fertilization for pine plantations. Treatment plots must be isolated by buffer zones that are wide enough to prevent roots of measurement trees in one treatment from drawing nutrients from another treatment or from untreated areas adjacent to the plot. Inadequate isolation may lead to erroneous or inconclusive results. It is common in these experiments for buffer areas to occupy three or more times the area as the measurement plots. Another problem is that areas of uniform soil of sufficient size to establish such trials are difficult to find.

An alternative to conventional field-plot procedures to develop response curves or surfaces is the continuous variable design (Fox 1973) in which individual plants in a row receive increasing amounts of the nutrient under study. Levels and combinations of two nutrients may be tested by increasing rates of application of the second nutrient at right angles to levels of the first. Thus, nitrogen application might increase incrementally from east to west and phosphorus from north to south. All combinations of many levels of each nutrient could be applied to a relatively small area of uniform soil. This is an economical way of screening fertilizer rates for an array of soils. No isolation between treatments is provided in the continuous variable design, since it is assumed that a plant in the middle of the treatment cell will extend its roots equally into adjacent cells and respond as though the entire root system had receivedone rate of fertilizer.

In 1981, the Timber Management Research Work Unit Alexandria, LA, initiated a study to test this technique on two sites in central Louisiana, This paper describes the design of these trials and reports preliminary results for one of the sites.

DESIGN OF EXPERIMENT

Since pines are a perennial crop and response of pine plantations to fertilizer extends beyond the first year, the basic technique was modified to achieve the following objectives: (1) to occupy the site with trees as early as possible in the experiment; (2) to measure aboveground biomass response to fertilizer levels during the course of the study; and (3) to provide final crop trees with ample growing space to reach a dbh of about 13 cm (5 inches) without undue competition from their neighbors. Another important consideration in modifying the technique was that response to small additional increments of fertilizer is apt to be greater at low than at high rates of application.

In our experiment we are testing 11 levels each of N and P. Nitrogen rates range from 10 to 1000 kg/ha and phosphorus rates from 5 to 500 kg/ha.

[1/] Paper presented at Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Rates increase linearly on a logarithmic scale with each succeeding level being approximetely 1.6 times the next lower one (fig. 1).

Each N-P combination was applied to a 2.0 by 2.0 meter area (4.0 m^2). The trees comprising the final crop are planted in the center of these cells. Nitrogen was supplied as urea (46-0-0) and phosphorus as triple superphosphate (0-46-0).

Amounts of each nutrient to be applied to individual treatment cells were carefully weighed on a laboratory balance and placed in packets. Contents of the packets were broadcast by hand evenly over the treatment cells. To facilitate location of individual cells, these boundaries were outlined with twine and their corners marked with wire pin flags.

The 22 by 22 m measurement plot is surrounded by a 2-cell (4 m) wide buffer, which increases the size of an installation to 30 by 30 m. Cells in the buffer area were fertilized at the same rates as adjacent cells in the measurement plots.

Obviously, seedlings at 2.0 m spacings will not occupy the site immediately. Nor are 121 trees an adequate number to allow individuals to be harvested periodically to measure intermediate responses to fertilizers. To overcome these deficiencies we planted additional trees 1.0 m apart on the boundaries between cells and at the center of each of the four 1.0 x 1.0 m quadrants comprising the 2.0 x 2.0 m cell. This reduced initial spacing between individuals to 0.71 x 0.71 m.

Harvest after 1 year will remove all trees in the centers of the meter square quadrants and increase spacing between residual trees to 1.0 x 1.0 m. Two options are available for spacing of residuals after the second harvest: removal of alternate rows of trees parallel to the x or y axis of the plantation would produce a 1.0 x 2.0 m rectangular spacing, whereas removal of alternate rows oriented diagonally to one axis or the other would result in a uniform spacing of 1.41 m between residuals. We specified the retangular spacing in the study plan but now favor the square arrangement. The third harvest will remove all remaining non-crop trees and increase spacing between individuals to 2.0 x 2.0 m.

Measurement plots contained 1,013 trees initially. The number will be reduced to 529 trees by the first harvest, to 253 by the second harvest, and to 121 by the third harvest.

Trees scheduled for intermediate harvest will be retained in the stand if they are needed to replace designated leave trees that have died. These replacements will be chosen at random from surviving trees in planting spots immediately adjacent to the missing trees.

The opportunity also exists to replace slow growing individuals with one of their more vigorous neighbors. Reducing variation in this way would alter the population to which results apply. Evaluating positive and negative consequences of this procedure must precede any decision to replace living trees with individuals scheduled for harvest.

Fertilizer rates in this experiment, directly apply only to the middle trees of each 2.0 x 2.0 m cell. But, the nutrient environment of any individual in the plantation at any time can be uniquely described by the x and y coordinate of its location. Moreover, use of coordinates rather than actual N and P rates will eliminate bias introduced by selecting individuals other than the center tree as crop trees.

Coordinates have the added advantage that they are proportional to the logarithms of fertilizer rates and need not be transformed for regression analyses.

Total height and groundline diameter of each tree on the measurement plot will be measured at the end of each growing season. Diameter at breast height may be substituted for groundline diameter after all trees attain a total height greater than 1.37 m (4.5 feet). Dry mass of foliage and woody material (bole and limbs, including bark) will be determined for each harvested tree. From these measurements we can derive volumes and total aboveground biomass of every tree, if such are desired. Foliage and woody material will be analyzed in the laboratory for N and P and perhaps for other nutrients.

Multiple regressions will be fitted to the response surfaces produced by the measurements listed above. Because rates of response to N and P are expected to decline and may become negative as application rates increase, and because interactions between N and P fertilization may be important, an equation having the form:

$$Y = b_0 + b_1N + b_2P + b_3N^2 + b_4P^2 + b_5NP$$

was selected as the response model. Terms are added sequentially in the order listed so long as they improve the fit of the equation to the response surface. In the equation, Y is a growth parameter (height, diameter, biomass, or nutrient content) and N and P are fertilizer rates expressed as actual amounts per unit area or their logarithms. Derivatives of the equations will be solved for amounts of N and P required for maximum response.

INTERIM RESULTS

Now let us lookatpreliminary results from an installation that was planted in June 1981 and fertilized in April 1982. Seedling heights and groundline diameters were measured in late August 1982, four months after fertilizers were applied.

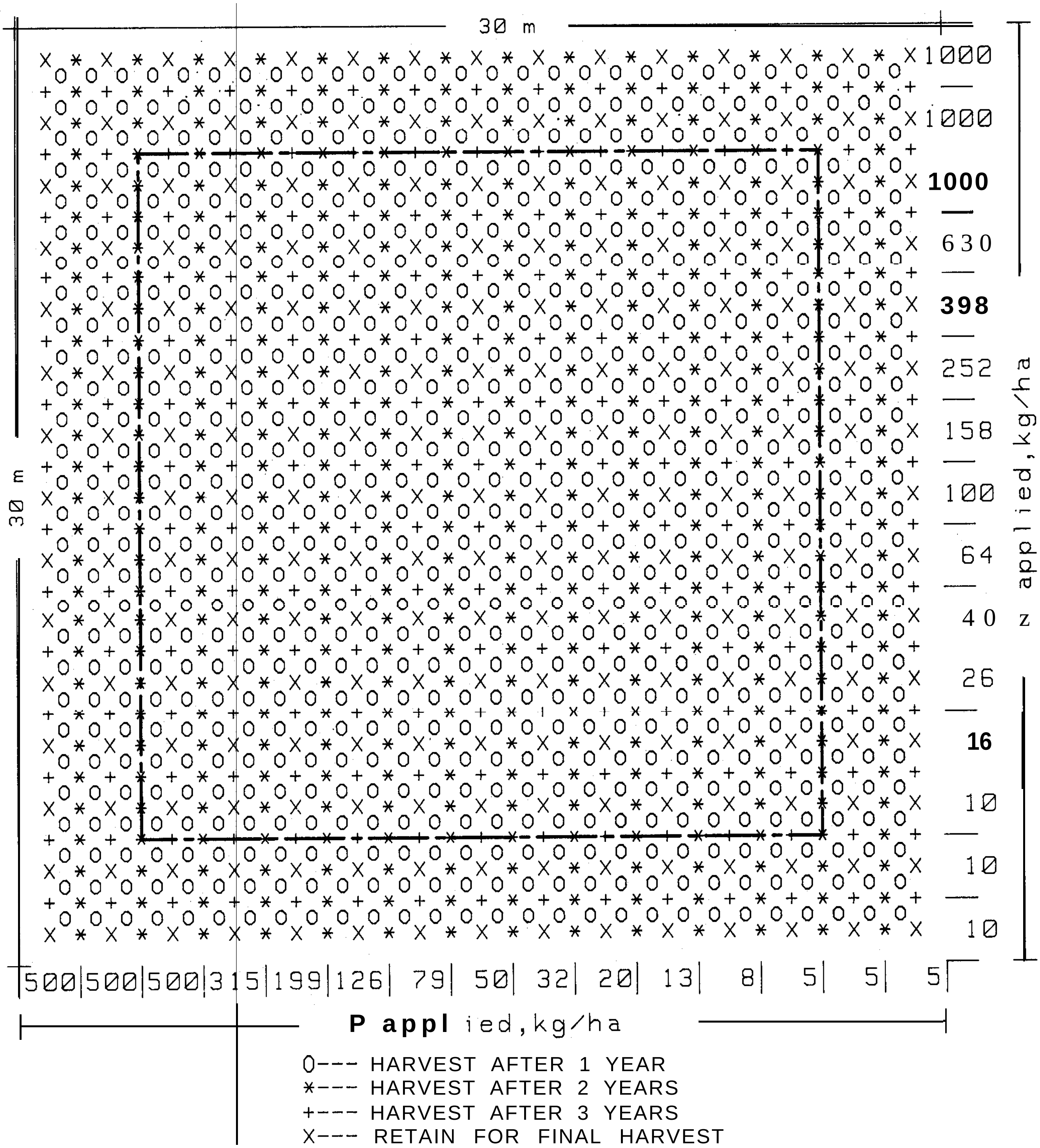

Figure 1.--Layout of test plantations. The "x" trees are centered in individual fertilizer-level cells. Fertilizer rates are shown at the bottom and on the right margin.

The site of this installation had never been tilled or fertilized. Soil is Beauregard silt loam (Plinthaquic Paleudult, fine-silty, siliceous, thermic). The test spacies is loblolly pine (*Pinus taeda* L.).

Laboratory analyses of soil samples from the 121 crop tree positions in the installation showed normal variation among samples but no important gradients in percent organic matter, nitrogen, or phosphorus.

Planting stock for the installation was grown in containers from wind pollinated seed from a single loblolly pine parent whose progeny had responded well to fertilization in greenhouse trials. Seedlings were 14 weeks old from seed when planted.

Plantation culture (in addition to fertilization) includes complete control of competing vegetation with herbicides supplemented by hoeing, and protection of seedlings from fusiform rust infection (*Cronartium quercuum* (Berk.) Miyabe ex Shirai F. sp. *fusiforme*) and Nantucket pine tip moth (*Rhyacionia frustrana* Comst.) damage with fungicides and insecticides.

Both heights and groundline diameters showed positive responses to N and P which culminated within the range of rates of application of the two nutrients (figures 2 and 3). There were no significant interactions between nutrients in their effects on growth. Even though only 4 months had elapsed since fertilizer was applied, the second-order polynomial regression accounted for 39 percent of the variation in tree heights and 30 percent of the variation in groundline diameters.

Only 21 kg/ha of nitrogen were required for maximum height growth and only 30 kg/ha for maximum groundline diameter growth. Corresponding quantities of P for maximum response were 211 and 150 kg/ha. While these values will undoubtedly change as trees have more time to respond to their nutrient status, they are excellent examples of the advantage of the continuous variable approach over conventional fertilizer trials for initial screening of fertilizer rates. A 3^2 factorial experiment that tested 10,64, and 158 kg/ha of N and 5, 32 and 79 kg/ha of P would have produced similar results for N but would not have determined the amount of P required for maximum response.

SUMMARY AND CONCLUSIONS

The continuous variable design allows the application of many levels of two treatments on a relatively small land area. The treatments must be continuous rather than discrete, so the method adapts well to fertilization trials but not

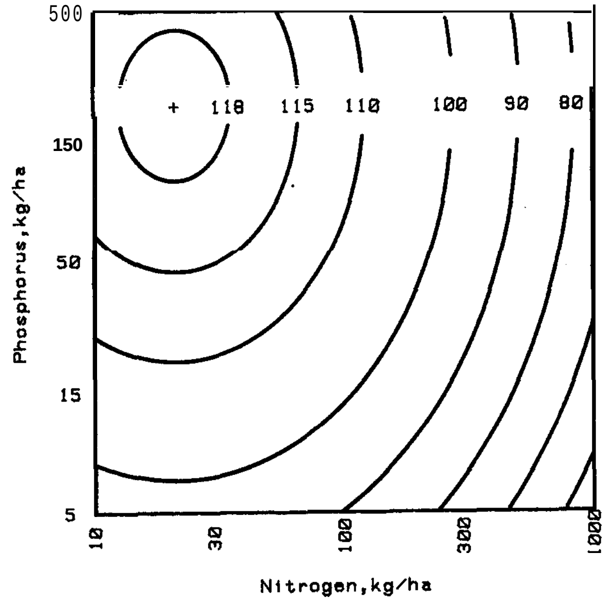

Figure 2.--Effect of nitrogen and phosphorus on isoquants of tree heights (in centimeters) at 14 months, four months after fertilization. Equation is:

$$Ht = 47 + 39 \text{ Log } P - 8.4 (\text{Log } P)^2 + 40 \text{ Log } N - 15.1 (\text{Log } N)^2 \text{ with } R^2 = 0.39$$

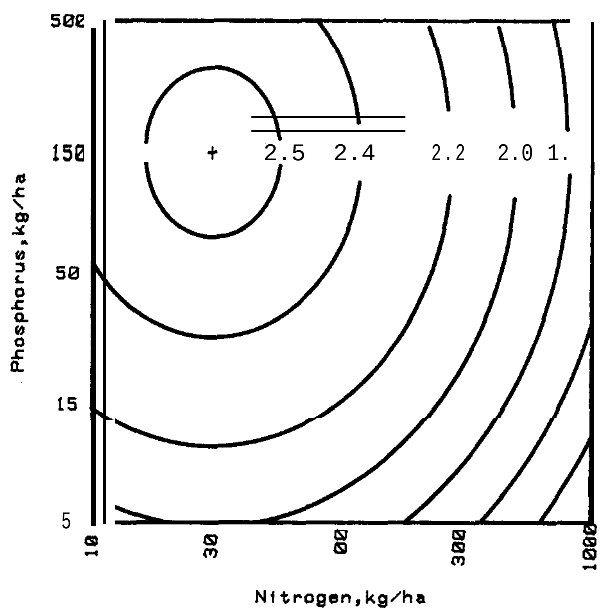

Figure 3.--Effect of nitrogen and phosphorus on isoquants of root collar diameters (in centimeters) at age 14 months, four months after fertilization. The equation is:

$$Rcd = 0.63 + 1.03 \text{ Log } P - 0.24 (\text{Log } P)^2 + 1.05 \text{ Log } N - 0.36 (\text{Log } N)^2 \text{ with } R^2 = 0.30$$

to tests of genetic materials. The advantages of the method are:

1. A large number of levels can be used in one experiment so that extreme levels can be applied. While the extreme levels may not be of practical significance, they are useful in describing the response curve.

2. The application of two treatments in an orthogonal design allows the study of potential interactions to a degree that is not possible with conventional field experiments which have a limited resource restriction on plot numbers.

3. By restricting the land area required, the task of finding uniform sites is easier.

4. The small size of the experiment reduces the labor and other resource requirements, so multiple sites can be installed. The design can be feasibly replicated in time and space, enhancing the reliability of the data.

As the study has been installed for a short time, all unforeseen problems have not shown up yet. Potential disadvantages are:

1. The inherent assumption is that roots will grow without bias in all directions. If a treatment affected root growth, the results may not reflect the true situation. For example, if phosphorus were to enhance root growth towards the side receiving the higher levels of phosphorus, the requirement for phosphorus would be underestimated.

2. Because each tree is in a sense a plot, tree to tree variability caused by genetics or microsite differences could mask the results. (Vander Zaag et al 1980).

3. The absolute requirement for a uniform site restricts the method to newly planted trees. Older plantations with their larger spacings would require too much land to meet the uniform site requirement.

While the results so far are encouraging, the study will have to grow through several more seasons before the application of the continuous variable design can be recommended for forest fertilization studies.

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THE COMPETITION-RELEASE ENIGMA: ADDING APPLES AND ORANGES AND COMING UP WITH LEMON&'

Shepard M. Zedaker[2/]

Abstract.--Much of the success in reforestation as a silvicultural operation depends on our ability to identify, evaluate, and manage competition from non-crop species. Unfortunately, our knowledge of the competition-release - growth response relationships in Southern forests is limited. Present methods to evaluate interspecific competition are only semiquantitative and make use of competition for space, size-density interaction, techniques developed for monocultures. But because plant competition is for the elements that space contains, i.e. light, water, nutrients, and not the space itself, differential resource use by various plant species limit such methods. Significant gains in our ability to evaluate competitive stress and predict growth response due to interspecific competition could be made if expressions of size and density of competing species were more indicative of their site resource use. An approach to evaluating competition and respoxise to release in loblolly pine plantations employing leaf area of competing plants is discussed. Since it controls light extinction in plant canopies, is directly related to water uptake and transpiration, and influences nutrient use, leaf area used as a bioassy of competitive stress should improve growth predictions in mixed species stands.

INTRODUCTION

The mere presence of an organism alters the environment of its neighbors and may result in changes in their growth and form (Harper, 1977). The process through which plants interact in this manner has been defined as competition. Competition is of interest to silviculturists because of its influence on growth and yield. Intraspecific competition has a profound effect on diameter distributions and product yield once the crop is established and dominant on a site. Prior to stand closure, the crop can be subject to interspecific competition that inhibits growth and in some instances can result in crop failure. Release, the selective control of forest weeds in a stand of crop trees, is used to relieve stress from interspecific competition. Ostensibly, the amount of crop growth improvement is related to the amount or quality of release. But, since the cost of weed control is directly proportional to the amount of vegetation killed, it may not be desirable, or even feasible, to control all non-crop vegetation.

The first step in optimizing release operations is understanding competition control-growth response relationships. Solution of the enigma imposed by interspecific competition in regenerating forest stands is exceeded in difficulty only by the proverbial problem of adding apples and oranges and coming up with lemons. Variation in site conditions, vegetative communities, site preparation, and timing of plant establishment results in a complex matrix of species interactions. This paper presents an untested yet tractable solution to the competition-release question. Because of its causal link to the functional environment,

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leaf area is proposed as the common denominator for species comparisons. Both theoretical and practical implications of the use of leaf area are discussed. The review which follows is intended to provide the reader with the background and basis for this approach.

COMPETITION AND THE FUNCTIONAL ENVIRONMENT

Definitions of plant competition have been numerous. Donald (1963) combined many of these into a concise statement:

> Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms.

For plants, these factors are light, water, and nutrients. Although references to "competition for space" occur in the plant literature, the phrase really implies that competition is for the elements that space contains (Zimdahl, 1972). This space-element concept sets plant competition apart from animal interactions. Exclusive of perhaps allelopathy, plant competition is purely an indirect process. Competition arises from the changes in the functional environment of one plant as influenced by the presence and growth of its competitors. Because forest communities rarely expand to the point where all potential crown or rooting volume is occupied by plant tissue, an actual struggle between competing plants for space or "territory" seldom occurs (Curtis, 1970). Thus, competition is a result of plant density and size relative to the available pool of resources rather than *geometric* space alone.

Differential consumption of site resources makes plant competition a difficult process to quantify directly. Proof of the causal link between the growth of some individuals, resource depletion, and the reduction in the relative growth rate of others has rarely been observed (Ford, 1975). Further, confounding competition-release relationships is interaction between above and below ground subsystems. Clearly, competition for light occurs only when plant populations are sufficiently dense for their crowns to shade one another. Yet, because of the continuous nature of the soil matrix, competition for moisture and *nutrients* undoubtedly occurs even when roots do not overlap. Experiments with mixed stands of pasture plants have indicated that significant interactions between above and below ground competition occur (Donald, 1958; Aspinall, 1960; Snaydon, 1971).

Interactions also exist between competition for different factors within the resource pool. A reduction in the supply of one element due to competition may result in a decrease in the ability to exploit the supply of other elements (Table 1).

The pool of available *resources* can be thought of as the functional or operational environment of a particular plant. This concept was introduced by Mason and Langenheim (1957). They defined operational environment in the statement:

> It must be continually emphasized that the operational environment is always the environment of a particular organism. There is no aspect of environment, in the sense of actively operating phenomena, that is not related to individual organisms . . . There are no phenomena significant to such aggregates of floras except as logical products or summations of phenomena operationally significant to the included or associated individuals.

In the context of competition, resources are operationally significant only if changes in their level of availability elicit a response in terms of plant growth. An example will clarify the meaning of operational significance.

Suppose that the mean soil moisture potential in a loblolly pine (Pinus taeda L.) plantation on August 20, 1982 was -1 MPa at 10 cm below the soil surface. What does this mean in terms of a loblolly pine's operational environment. Really very little. An individual pine responds or senses the highest soil moisture potential (least moisture stress) to which its root system has access, which might be quite different than the mean potential at 10 cm. Furthermore, the soil moisture potential on August 20 may elicit very little response in terms of tree growth. Plants have mechanisms, such *as* stomata1 *control,* solute concentration, and stem water storage, that alter the effects of a particular day's water regime. Loblolly pine exhibits both elastic and plastic responses to moisture stress. Because we are interested in the plastic or growth response, integration of the sensible moisture regime over an entire growing season is the only operationally significant environmental factor in terms of the available pool of water.

Significant gains in our understanding of the competitive interactions of forest trees could be made if competitor growth were treated as an indirect factor working through the functional *environment* to influence subject *tree* growth. Connections between plantation site/climatic effects, competitor species growth effects, alterations to the functional environment of the crop, and subsequent effects on crop growth would require identification. These connections could be viewed as a path analysis model to illustrate crop behavior (fig. 1). The construction of the model followed the procedures for analysis of causal paths outlined in Turner and Stevens (1959) and described for observational data on natural systems

Table 1.--Effects of competition for light and water by an aggressor species (A) on a suppressed species (S)[1/]

Effects	Competition for Light	Competition for Water	Competition for Light and Water
Primary	(1) A reduces light availability to S	(3) A reduces water availability to S	(1+3) A reduces light and water availability to S
Secondary	(2) Lower light supply reduces the ability of S to exploit its water supply	(4) Lower water supply reduces the ability of S to exploit its light supply	(2+4) S suffers reduced capacity to exploit light and water supply
Interactions	(1) x (2)	(3) x (4)	(1) x (2), (1) x (3), (1) x (4), (2) x (3), (2) x (4), (3) x (4), (1+3) x (2+4), . . .

[1/] After Donald, 1958.

by Overton and Florschutz (1962). Climatic site variables are introduced as primary factors, functional environmental variables and competing vegetation are described as intermediate resultant effects, and crop growth is the ultimate resultant effect. Variable sums are the integration of environmental attributes over a growth cycle. Feedback vectors are included since the functional environment both affects and is affected by competing plants.

The path analysis model provides the physical and biological framework for explaining how the process of interspecific competition takes place, but cannot be used directly to solve the enigma. The crux of the functional environment solution

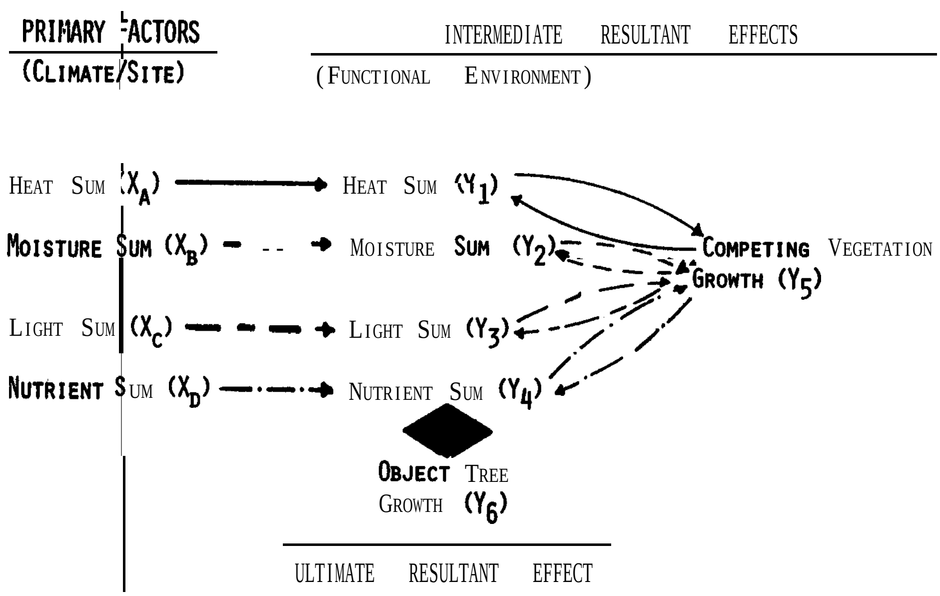

Figure 1.--Path analysis model of relationships between climate/site factors, an object tree's functional environment and competing vegetation.

is our inability, at least with current technology, to measure the operationally significant variables. The complexity of the functional environment matrix, the physical difficulty of measurement without influence, and the drastically different above and below ground subsystems provide formidable barriers.

BIOASSAYS IN COMPETITION STUDIES

When presented with measurement problems, such as is the case with a plant's functional environment, researchers often resort to a biological assay technique. A bioassay is used when the measurement of a causal agent is difficult but the effect it has on a biological system is uniform and predictable. Silviculturists have been using bioassay techniques, although somewhat unknowingly, for some time in their attempts to develop competition-density indices for forest growth.

Competition-density indices, such as Opie's Competing Basal Area, Bella's Competition Influence Zone Overlap, and Arney's Competition Stress Index, are derived from relationships between size of the crop tree, competitor size, and proximity of competing stems (Table 2). The variables which comprise these indices, i.e. number of competitors, crown area overlap, basal area of subject tree and competitors, number of trees per acre, etc., describe in a round-about manner the functional environment of the crop trees. Unfortunately, competition-density indices are often treated as magic numbers that, when entered into growth equations, "explain" what goes on in the nebulous competition black box. Little attention is given to the underlying principal that makes such indices relatively successful for describing the effects of competition in the even-aged monocultures for which they were developed. In single-species stands, access to and control over the pool of site resources is directly proportional to plant size (Newton, 1973). Within species variation in the efficiency of resource use is minor in comparison to differential consumption relative to an individual tree's basal area, height, or crown volume. This principal makes competition-density indices good bioassays for the causal agent, the subject tree's functional environment in monocultures.

The same cannot be said for the mixed-species stands creating the competition-release enigma. In these stands, differences in species growth rates, canopy and root system structure, and production efficiency results in a complex matrix of differential consumption of site resources. Research in agronomic crops has indicated that water use efficiency in dry matter or volume production varies considerably between species, but

Table 2 .--Competition-Density indices used for even-aged monoculture forest growth modeling.

Author (date)	Index	Independent Variables[1/]	Percent of Variation in Dependent Variables Explained
Amey (1973)	Competition Stress Index	n, ak, A	*[2/]
Bella (1971)	Competition Influence Zone Overlap	n, ak, BAF	57
Drew and Flewelling (1977)	Relative Density Index	n, $\bar{V}$	*
l-loner (1972)	Point Density Measure	HT, CD	*
Krajicek et al. (1961)	Crown Competition Factor	AR, Di, Ni	*
Moore et al. (1973)	Area Potentially Available	n, ak, A, DBH, di	76-66
Opie (1968)	Competing Basal Area Count	n, ak, A, BAF	55
Tennent (1975)	Competition Quotient	n, ak, A	81

1/ n=number of competitors , ak=crown area overlap with kth competitor, A=subject tree crown area, BAF=basal area factor, di=DBH of ith competitor, DBH=DBH of subject tree, CD= subject tree diameter, V=mean tree volume, AR=area in acres, Ni=number of trees in DBH class, Di=DBH class.

2/ *Not given in report.

is relatively constant within species (Hillel, 1971). Miller and Poole (1979) reported similar results in their study of the pattern of water use by woody shrubs. Two- to four-fold differences in transpiration rates per unit of leaf area among ten tree species infer that forest associates also differ in their efficiency of water use (Kramer and Kolowski, 1970). Species differences in photosynthetic efficiency are well documented (Bannister, 1976; Kramer and Kozlowski, 1979). Consistant variation among forest species in their nutrient content, on a dry weight basis, infers that differential consumption of nutrients occurs but does not provide conclusive evidence of differential productive efficiency (Rennie, 1955; Tamm, 1964; Marrison, 1974).

A pragmatic view of a hypothetical competitive situation results in similar conclusions. Suppose that a subject loblolly pine were growing one meter away on one side from a red maple (*Acer rubrum* L.) and one meter away on the other sdie from another loblolly. Both competitors with the subject loblolly have 10 cm* of basal area and are 3 meters tall. One competitor, the maple, is deliquescent while the other exhibits an excurrent crown form. The maple is deciduous and casts significant shade for only a portion of the year. One competitor is distinctly taprooted, the pine, while the other has a more fiberous spreading root system. It is obvious that the effect of the maple on the subject loblolly's functional environment is quite different from that of its specific twin. In this case, an attempt to use conventional competition indices based on plant size and proximity to predict growth response from release would be much like trying to add apples and oranges. The result would probably be a lemon of a prediction.

LEAFAREA- THECOMMON DENOMINATOR

Solving the competition-release enigma depends on finding a common denominator for adding the apples and oranges of our mixed species stands. To be effective, the denominator must meet three criteria. It should adequately reflect the effect of plant size and species on the functional environment of our crop trees. It must be easy to determine in the field so that silviculturists can assess the competitive status of their plantations and make recommendations for release prescriptions. The denominator must also be amenable to improvement as a bioassay when research provides better links between it and the functional environment causal agents. I hypothesize that leaf area is the common denominator which can be used to solve our enigma.

Leaf area is primarily responsible for the light environment of croptrees. We can determine the amount of light intercepted by plant canopies using:

$$S_b(L) = S_b(0)e^{-K_s L}$$

where: $S_b(L)$ = the direct solar radiation measured on a horizontal plane below a leaf index of L

$S_b(0)$ = the direct solar radiation above the plant canopy

and K_s = shadow cast by a unit area of leaf

This is simply a special case of Beer's Law (Monteith, 1973). Since the vast majority of water used by plants is transpired through leaf tissue, leaf area should be indicative of the status of the moisture resource in the functional environment. Water use per unit leaf area has been determined for agricultural crops and forest trees. Although there is considerable variation in transpiration rates due to environmental influences, forest species exhibit different yet consistant water use patterns on a seasonal basis (Conard and Radosevich, 1981; Miller and Poole, 1979). The relationship between leaf area and nutrient use is less well defined. However, it is not unreasonable to expect that leaf area, through its direct relationship to the amount of photosynthate available for plant growth and to water uptake, would strongly influence nutrient use. Leaf area is probably better than any other single physical attribute at reflecting the influence competing plants may have on the crop's functional environment.

To meet the second criterion, leaf area must be easily measured in the field. Although direct measurement of the leaf area of individual plants would be an onerous task, indirect methods are available which provide accurate results. Carbon and others (1979) presented a method for visual estimation of leaf area in forest stands. By correlating visual estimation with measured standards, experienced estimators were able to determine leaf area index in Eucalyptus stands in Australia within four percent.

A more rigorous method, not dependent on estimator expertise, is based on the hypothesis that a physiological balance exists between plant conducting tissue and water requirements as determined by leaf area. Stem diameter has been used to estimate foliar weight or area since the mid-sixties (Whittaker and Woodwell, 1967). For conifers, linear correlations of tree stem dimensions with leaf area/weight are generally better if sapwood area is used rather than dbh (Table 3). This is because heartwood, which could make up a large portion of total basal area, contributes little to water transport through the stem. Further restriction to current sapwood area, defined as the present spring wood and last year's growth ring, improved estimations for oaks (Rogers and Hinkley, 1979). This is because water flow in oak is restricted to the most recent one or two growth rings. Similar relationships between foliar area/weight and stem conducting area may be expected for other species.

Table 3.--Linear 'regression attributes for estimating leaf area/weight for selected forest tree species.

Species	Dependent Variable Y[1]	Independent Variable X[2]	Number of Samples n	Coefficient of Determination r^2 (%)	Reference
Abies lasiocarpa	FW	spa	8	93	Kaufman & Troendle, 1981
Acer macrophyllum	Fw	dbh	18	87	Grier & Logan, 1978
Pinus contorta	Fw	dbh	19	84	Reid et al., 1974
	Fw	spa	9	95	Kaufman & Troendle, 1981
Pinus monticola	Fw	dbh	11	93	Snell & Brown, 1978
	FW	spa	11	98	Snell & Brown, 1978
Populus tremuloides	Fw	spa	11	97	Kaufman & Troendle, 1978
Pseudotsuga mensiesii	Fw	dbh	123	86	Grier & Logan, 1978
	Fw	spa	18	96	Snell & Brown, 1978
Quercus alba	Fw	spa	12	70	Rogers & Hinckley, 1979
	Fw	csa	12	98	Rogers & Hinckley, 1979
	FA	spa	12	75	Rogers & Hinckley, 1979
	FA	csa	12	94	Rogers & Hinckley, 1979
Thuja plicata	Fw	dbh	6	91	Waring et al., 1978

[1] FW = Total tree foliage weight, FA = Total tree foliage area.

[2] dbh = Diameter breast height, spa = sapwood basal area, csa = current sapwood basal area, i.e. last two growth rings.

Once conducting area - foliar area regressions are derived, the use of leaf area as a common denominator in studies of interspecific competition is easy. Silviculturists could substitute leaf area for basal area or dbh, or use a weighting factor that reflected leaf area, in their computation of competition indices. Measurement of leaf area in regenerating stands would consist of measuring basal diameter/area of competing stems. Since, for the first few years after establishment all stemwood is sapwood/conducting tissue, no separate heartwood-sapwoodiestimation would be needed. Thus, leaf area could be easily estimated in the field, satisfying criterion two for a good common denominator.

Although leaf area is a better estimate of environmental influence than dbh or basal area, it still is not perfect. Species differ in the amount of water transpired per unit of leaf area. Variation in leaf orientation and shape between species cause differences in light extinction under their crowns. As physiologists improve our knowledge of specific resource use per unit of leaf area, competition indices using leaf area can be enhanced. Weighting factors for light, water and nutrient use could be applied to leaf area to better model its influence on the crop tree, functional environment and meet criteria three.

A COMPETITION-RELEASE STUDY

To test leaf area as a common denominator and shed some light on the competition-release enigma, I have designed a study which will be installed in the summer of 1983 in loblolly pine plantations in Virginia. The objectives of this work are:

1. To develop objective measures of competition in pine plantations based on: size, proximity, numbers, species and control of site resources through leaf area by competing vegetation.

2. To quantify the competitive status of plantations created by site preparation and various levels of release for loblolly pine establishment.

3. To use the measures developed in objectives 1 and 2 above to predict early growth and response to release of loblolly pine in plantation environments.

Competition and response to release will be evaluated at the stand level as well as on a single tree basis. For stand level evaluations and to

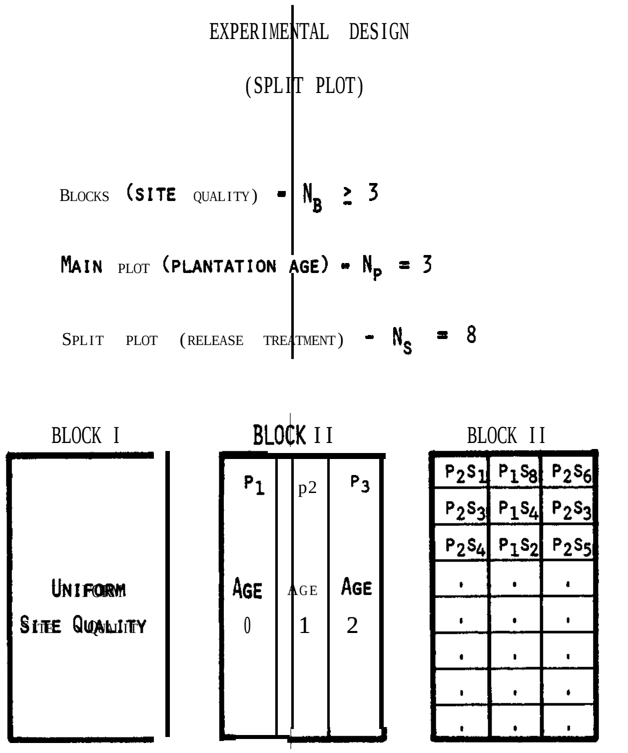

Figure 2.--Experimental design and plot layout for competition-release study in loblolly pine plantations.

create variation in competitive status for individual tree growth prediction models, a split plot experimental design will be used (fig. 2). A minimum of three replications of the whole experiment are planned. Blocking will be done on the basis of site quality or geographic location. Within each block, plantations of three ages, 0, 1, and 2 years after planting will be subject to release treatments. These release treatments are:

1. No competition control
2. Herbaceous weed control
3. Woody stem control
4. Herbaceous weed and woody stem control
5. Control of 1/3 of the woody stems
6. Control of 2/3 of the woody stems
7. Control of herbaceous weeds and 1/3 of the woody stems
8. Control of herbaceous weeds and 2/3 of the woody stems

All competition control will be provided by herbicides. Repeat treatment will be applied as necessary to insure single season control. Mechanical disturbances of the vegetation will be avoided because of the confounding effects of resprouting and immediate shade removal.

Stand level response will be determined by measuring average height, diameter and volume growth for pines and hardwoods in each split plot. The development of predictive equations of seedling growth will require the establishment of single tree plots in each treatment split plot. Competitive status of individual loblolly pine will be evaluated on the basis of size, proximity, numbers of individuals, species, and leaf area for competitors within polygons of influence around each tree. These attributes, along with pine height and basal diameter, will be measured before treatment and yearly following release until pine crown closure. Regression analysis will be used to evaluate the relationships between measures of competition and loblolly volume growth. The growth models developed will be evaluated for variable sensitivity with emphasis placed on the development of an easy-to-use field technique to evaluate the need for, and response of trees to, release.

This study should improve our ability to identify, evaluate, and manage competition from non-crop species in loblolly pine plantations. Although it may not provide the ultimate solution to the competition-release enigma, it should make adding the apples and oranges of our mixed species stands less difficult.

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SOUTHERN PINE BEETLE HAZARD RATINGS: USES, IMPLEMENTATION, AND EVALUATION[1]

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Abstract.--Stand hazard rating systems are being applied to direct and indirect approaches of southern pine beetle management. Uses, application approaches, and interpretation of rating results are discussed.

INTRODUCTION

Numerous southern pine beetle (SPB), *Dendroctonus frontalis* Zimmermann, outbreaks have occurred in the 13 Southern States since the beetle was first described in 1868 (Price and Doggett 1978). At times, they have occurred simultaneously in several States, causing widespread, often spectacular timber volume losses. This has disrupted normal operations, reduced potential yields from managed forests, and sometimes caused serious damage on small ownerships. Such losses can be reduced by properly managing pine and pine/hardwood forests and by using available technology for dealing with the SPB (Belanger and Malac 1980, Billings and Pace 1979, Swain and Remion 1981).

Historically, most efforts to control SPB have only provided short term relief (Thatcher et al. 1982). However, in the last 10 years, interest and support for developing approaches to prevent and/or reduce losses to SPB has increased. One approach involves the development and use of stand hazard ratings. Such ratings are needed in long range planning to maximize stand growth and yield and to minimize pest losses. They may also be used to better direct suppression efforts to stands with the greatest potential for loss.

This paper presents a general overview of how stand hazard rating systems are used to reduce SPB-caused losses, summarizes approaches that have been taken in developing and implementing hazard rating systems across the South, and points out things that should be considered in evaluating the usefulness or meaning of hazard ratings.

HOW HAZARD RATINGS CAN BE USED

Just as the quantity of forest fuel affects fire hazard, dense slow-growing stands have an increased potential for SPB attack and spot development. Basically, if beetles are present in an area, stands that have been identified as high hazard are more likely to be successfully attacked than are those classed as low hazard. If attacks occur in older densely-stocked stands, the chances are that timber losses and beetle numbers will be much greater than would be the case in a similar infestation in low-hazard areas. Since large, overmature, or sawlog-size trees are more often affected, the financial losses, should a spot occur, are also likely to be much more severe. An understanding of these relationships can be very useful in management planning and operations aimed at reducing beetle-caused losses. The following are some uses for hazard rating:

Hazard reduction. Prescribed burning has been used to reduce fire hazard for years. Knowledge of the distribution and abundance of high hazard stands provides a similar opportunity for reducing beetle hazard through silvicultural treatment. The timely thinning of stands before they become high hazard or even after they are high hazard can reduce their susceptibility to a lower level. Although few stands may be thinned for the sole purpose of preventing or reducing SPB losses, a knowledge of how stand conditions affect potential beetle risk provides additional criteria that can be used in establishing cutting budgets, reentry times, and harvest schedules.

Scheduling control operations. As forest managers become more familiar with pine bark beetles and their relationship to forest conditions, management practices and forest economics, they have come to recognize that some spots should

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receive immediate attention, while others can be left uncontrolled. Techniques have been developed for setting control priorities based on level of beetle activity and size and number of spots (Billings and Pase 1979). Knowledge of the nature and condition of the surrounding forest increases our ability to make control decisions that are biologically and economically sound.

Inventory/pest assessment. In east Texas, during the period 1974-1980, an average of 0.5 percent of the land on a 240,000-acre area was classified as very high hazard, 9.5 percent as high, 27 percent as moderate, 26 percent as low, 6 percent as very low hazard, and the remaining 31 percent as nonhost hardwood, clearcuts, and nonforested areas. Many ownerships in other areas of the South would probably have similar conditions. Further, holdings with more intensive management would probably have a greater proportion of low-hazard stands, while those with little or no management, or with management objectives other than timber, would have a larger proportion of high-hazard stands. If this holds true, other things being equal, ownerships with a predominance of low-hazard type should have, on the average, less severe beetle problems over time. Hazard rating gives the landowner the opportunity to make these judgments and to determine the need for direct control and/or stand management actions.

Beetle population removal. Removal of infested trees from high-hazard areas can provide more immediate benefits than the long term gains from intensified stand management. Survival of the SPB during endemic periods appears to be strongly dependent upon the availability of suitable host material. When activity is low, most spots occur and spread in very high-hazard (optimal habitat) stands. As beetle activity intensifies, spots spread into less favored (low to moderate susceptibility1 stand types. However, when activity again declines, and survival becomes a critical factor, populations once again concentrate in high-hazard areas having older, denser, slow-growing stands as well as diseased trees, trees attacked by other beetle species (Ips etc.), and stands under stress from man-caused or natural events (e.g., drought, lightning). It is believed that these "reservoir" stands serve as epicenters for future outbreaks when environmental conditions are again favorable for beetle population development. Timely harvesting of these stands during low beetle activity (endemic) periods could prevent or slow the development of future outbreaks by removing sources of beetles which provide potential for population buildups.

SPB survey. Even during endemic periods, surveys are necessary to detect or evaluate infestation incidence, location, and severity. Detection flights commonly cover large areas and may reveal little or no apparent activity. Such surveys can be made more efficient by concentrating on "reservoir" or high-hazard areas during endemic periods. If no activity is found there, it is safe to assume that there would be no activity in low- or medium-hazard stands. As beetle activity increases in these "indicator" areas, the survey can be expanded to include less susceptible pine and pine/hardwood stands.

IMPLEMENTATION APPROACHES

We recognize that if new pest management technology (in this case, hazard ratings for SPB) is to be accepted and used, it must be packaged in readily understood form, be cost effective, require little extra labor, and complement existing forest management efforts. During the Expanded Southern Pine Beetle R&D Program, researchers across the South collected the necessary site-stand data needed to develop stand hazard rating techniques for a variety of site and stand conditions (Coster and Searcy 1981). These and other studies resulted in a number of hazard rating approaches (Belanger et al. 1981, Hicks et al. 1981, Mason et al. 1981, Ku et al. 1981, Lorio 1978, and Sader and Miller 1976). Several of these systems have been implemented by State, Federal, and industrial forestry organizations (Table 1).

The following approaches have been taken in implementing hazard rating systems:

Application based on existing stand data. Most managed forest ownerships maintain tract survey, management unit, and stand type maps for which inventory information is available. These records generally include data necessary to rate stands, or information from which these data can be derived. Computer storage and retrieval offers acquisition convenience and continuous update capability, and represents the ideal data base situation for SPB hazard rating. Stands may be classed manually from computer printouts, directly from stand maps, or automatically after entering the appropriate rating equation. To date, this approach has been applied largely to National Forest lands (Lorio and Somners 1981). Continuous Inventory of Stand Conditions (CISC) is an automatic data-processing system employed by the National Forests in the South to document timber stand conditions. By using five data fields in CISC (forest type, stand condition class, method of cut, operability, and site index), a rating of high., medium, or low hazard can be developed for SPB attack. Six hundred thousand acres have been hazard rated on the Kfsatchie National Forest and the information is currently being used, along with traditional criteria, to select stands for regeneration and intermediate cuts.

The same hazard rating system, along with an annosus root rot hazard rating system, is being implemented on 128,000 acres of the Holly Springs National Forest in Mississippi. This cooperative

Table 1.--Implementation of hazard ratings for SPB in the South

State	System Developed by	Technology Directed To	Organizations Involved in Implementation
Arkansas	Ku	Small, private, nonindustrial	U. Arkansas-Monticello Arkansas Forestry Comm.
Alabama	Mason/Hicks (Coastal Plain) Sader/Miller (Piedmont)	Small, private, nonindustrial	Alabama Forestry Comm.
Georgia	Belanger	Small, private, nonindustrial	Southeast. For. Exp. Stn. Georgia Forestry Comm.
	Hedden	Ga. State Parks	Georgia Forestry Comm Georgia Dept. Nat. Resources Clemson U.
Louisiana	Lorio	National Forests	Kisatchie NF Southern For. Exp. Stn.
Mississippi	Lorio	National Forest	Holly Springs NF Region 8-S&PF
Texas	Mason/Hicks	Small private, nonindustrial Industry	Texas Forestry Serv. Stephen F. Austin U.
	Mason/Hicks	Temple EasTex	Temple EasTex Stephen F. Austin U.

effort between Region 8-State and Private Forestry, Southern Station, and Ranger District personnel will evaluate the different ways that hazard ratings and other technologies can be used in the Holly Springs District's ongoing prevention and suppression activities.

Application using aerial photographs. Applications of stand hazard ratings to large land bases, in the absence of existing stand inventory data, can be accomplished with aerial photographs (Mason et al. 1981, Sader and Miller 1976). Gross level stand identification suitable for SPB hazard rating can be acquired easily from small scale (≅ 1:60,000) color infrared photography. Detailed site and tree conditions within stands may be added using larger scale (1:12,000 to 1:5,000) sampling or ground examination.

A two-county demonstration area (approximately 1.5 million acres) in east Texas has been hazard rated as a part of a larger integrated pest management demonstration project. Color infrared 1:60,000 scale photographs have been used to delineate stand boundaries. Supplemental 1:12,000 color infrared and black and white resource photographs have been used to acquire necessary tree information. Landform/drainage conditions were extracted from 7 1/2 minute topographic maps. The resulting 40+ hazard maps were provided to industrial landowners and cooperating State foresters in the two-county area for verification of stand and hazard conditions. More recently, the resource information on the maps has been digitized and stored for computer retrieval and updating as changes are reported from the various ownerships. State and industrial foresters are already using this new information to aid in stand selection for harvesting operations and, as a result of harvesting or thinning, to lessen stand susceptibility to SPB.

Application based on ground cruise results. For individual tracts of particular concern or small ownerships, ground observers can make onsite determinations of SPB hazard. A land managers model provides a simple qualitative system that uses stand, tree and site characteristics to rank stand susceptibility to SPB attack (Belanger et al. 1981). The system is compatible with procedures used to develop forest management plans and is curently being used by Georgia Forestry Commission foresters in the upper Piedmont of Georgia.

In Arkansas, a hazard rating system for **shortleaf/loblolly** pine types was developed for natural stands on upland flats (Ku et al. 1981). The key variables are total basal area, hardwood basal area, stand age, and radial growth during the last 10 years. The Arkansas Forestry Commission assisted with the data collection for model development and has sponsored training sessions for management assistance foresters on the application and utilization of the rating system. The foresters will consider **SPB** hazard rating in the development or revision of forest management plans.

Temple **EasTex,** Inc., a subsidiary of Time, Inc. and owners of 1.1 million acres of forest land in east Texas, has initiated SPB hazard rating as a part of their stand evaluation activities. The company reinventories 20 percent of its stands each year and is currently in the second year of a 5-year reevaluation effort. Stand rating is being incorporated into these activities. Only slight modifications of operational inventory procedures were required to obtain pine basal area, total tree height, and **landform** information required to rate individual stands. The ratings will allow company foresters to consider the potential for SPB losses in developing silvicultural prescriptions and in setting cutting priorities on company lands.

Besides using the continuous inventory data which is already on line for rating stands, the Kisatchfe National Forest foresters are using field data collected during the stand prescription to update their SPB hazard ratings. Forest stands on the Kisatchfe NF are reinventoried once every 10 years. Foresters will use those data in the same ways described under "Application based on existing stand data" above.

Application using combinations of tech- Data requirements of some rating **sys** em;, availability of funds, trainfnq **requirements** for responsible persons,-or size **of** land area to be rated may force resource managers to use field cruises as the only practical approach to hazard rating. However, this approach can be simplified by stratifying stands from aerial photographs, resource inventory data, or existing stand maps.

During 19804981, three Georgia State Parks (with a total area exceeding 8,000 acres) were hazard rated as part of an effort to develop more effective management plans for the park system. Stands were delineated from aerial photographs (scale **1:12,000)** to define host type and boundaries and to determine plot numbers and location. Four field plots were installed in each stand. Those stands exceeding 50 acres had one additional plot added for each 12.5 acres. Field data acquired included species composition, d.b.h., tree height, radial growth, bark thickness, and surface soil depth. Plot averages were then determined and the stand rating class assigned using Belanger's Piedmont system. Based on these ratings, modified timber management plans were developed for each park.

A similar approach has been applied by the Alabama Forestry Commission. Twenty-two demonstration forests have been selected for use in promoting preventive management of SPB. Foresters use existing forest-type maps to determine number of plots required per forest and to plan their most efficient hazard rating approach. The system developed by Sader and Miller **(1976)** has been used on the Alabama Piedmont (higher elevations) and that of Mason et al. **(1981)** for the Coastal Plain (lower elevations). Both systems are being used by Service Foresters and are required in all management plans developed for private nonindustrial lands. Hazard ratings will soon be incorporated into the Forestry Commission's **WOODPLAN** computerized management analysis program. The ratings will provide additional criteria on stand selection for preventive silvicultural treatments, as well as a means of demonstrating the utility of rating systems as a means of identifying high-hazard stands or setting priorities for surveillance or control throughout the State.

EVALUATION AND INTERPRETATION

Although there is a broad array of management objectives and forest conditions across the South, it has been demonstrated that, on a **per**-acre basis, most spots occur in high-hazard stands. A larger proportion of trees are killed in these stands **(Lorio** and **Sommers** 1981, Mason et al. 1981, Hicks and Mason 1982). Thus, the major objective in assembling a SPB stand hazard rating system for any geographic area or ownership should be to develop an optimal balance between the maximizing stand growth and yield and minimizing pest-caused losses.

One should not judge the adequacy of a rating system based on examination and rating of a few infestations without considering the overall situation in an area and possible overriding factors. Evaluation must include the ranking of a relatively large number of stands and consideration of total hazard class size and distribution, infestation distribution, and infestation size. Judgment should be based on a comparison of spot occurrence and tree mortality, resource value, and potential SPB reproduction in similar sized areas with and without infestations. If this approach is not taken, one should expect to find a large proportion of infestations in low- to moderate-hazard stands. This high proportion of infestations in non-high risk stands can result from factors known to override site/stand conditions (lightning strikes, ice damage., logging or storm damage., **areawide** drought or flooding, etc.). One must also be aware of high-hazard pockets in low-hazard stands. Also, the number, distribution, and proportion of infestations which occur in high-, moderate-, and low-hazard areas will vary as SPB population densities increase and decline (Mason et al. 1981). When beetle activity is low, most infestations will occur in high-hazard areas. When beetle activity and population pressures on stands increase, an increasing number of spots will occur in low and moderate-hazard stands.

The most common approach to dealing with a sporadic but serious pest like the SPB is to respond to the crisis directly on an ad hoc basis--often recognizing that long-term preventive management would be ultimately more effective. Stand hazard rating lends itself well to both long- and short-term needs. Stand condition may be considered in direct control by aiding in setting control priorities and assessing outbreak and loss potential. Indirectly it allows the manager to identify and evaluate areas in need of treatment and to more effectively monitor pest activity during endemic periods. Both approaches are necessary for effective pest management operations. Stand rating systems are available, beneficial, and are being applied in progressive forest management programs.

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EVALUATION OF LOBLOLLY PINE THINNING REGIMES FOR REDUCTION OF LOSSES FROM SOUTHERN PINE BEETLE ATTACK[1]

Roy L. Hedden[2]

Abstract.--A computer simulation program was used to project expected losses from southern pine beetle attack. The effects of thinning and rotation length on the reduction of expected loss were evaluated. Thinning of stands will result in the reduction but not elimination of losses due to attack. Shortening of the rotation length will always result in reduced losses from infestation.

INTRODUCTION

The southern pine beetle (~~SPB~~ Dendroctonus frontalis Zimmerman) is a chronic pest of southern pines. Periodic outbreaks lasting up to three years have been recorded since 1882 (Thatcher 1960). Recent outbreaks seem to be occurring more often and they seem to be of longer duration. A key factor appears to be the availability of susceptible hosts (Hedden 1978). In all regions of the South, the SPB prefers well to densely stocked, slow growing, pure pine stands (Belanger 1981). There are now more of these types of stands than ever before (Hedden 1978, Knight and McClure 1979, Murphy 1976).

The dynamics of SPB infestation are composed of two distinct events; spot initiation or occurrence and spot growth or spread. In all areas, trees or stands weakened by disturbance such as lightning or logging are very susceptible to initial infestation. Other factors which predispose stands to attack are also related to low tree vigor, including disease, overstocking, overmaturity, etc. The amount of spot spread which occurs after an infestation becomes established appears to be related to the SPB level within the spot, physiological condition of the beetle population and density of pines in the stand (Hedden and Billings 1979; Schowalter et al. 1981). More trees are killed in overstocked pine stands in years when the SPB population is high than at any other time.

Strategies for minimizing or preventing losses in pine stands must consider both initial spot occurrence and subsequent.spot growth. If no or few spots occur within a stand, little loss will result. This situation will occur in the absence of stand disturbance and in the presence of vigorously growing pines. Moreover, if stand density is low, subsequent loss due to spot growth will be minimum even if an infestation does become established.

Thinning of pine stands is one strategy suggested for minimizing or preventing loss due to SPB attack (Belanger 1981). Thinning should reduce stand susceptibility to attack by increasing tree vigor. The presence of rapidly growing trees will inhibit the build up of within spot SPB populations even if one or a few trees are attacked. Thinning will also increase inter-tree distances which reduce the amount of infestation spread following initial attack (Gara and Coster, 1968).

Unfortunately, there are few studies specifically designed to evaluate thinning for preventing or reducing losses from SPB attack. There are several reasons for this lack of experimental evidence. The probability of an infestation occurring in a stand is low, even in years of high SPB population level. For instance, during 1976 in east Texas when the highest SPB population ever, was recorded, a 100-acre pine stand had only a 2 out of 10 chance of having a single infestation. Thus, in order to directly evaluate thinning as a strategy, many paired thinned and unthinned stands would have been required. Moreover, SPB populations rarely remain at such high levels for long, and as population level declines so does the

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probability of infestation (Reed et al. 1982). Any direct test of thinning must, therefore, be of long duration. Unfortunately, few researchers have either the patience, support, or opportunity to implement and carry out such long-term experiments.

An alternative, but less direct approach, is to use a computer simulation to evaluate thinning as a strategy to prevent damage from SPB attack. While this approach is less desirable than a direct experimental test, it does not depend on the vagaries of beetle populations, nor is a large land area or high level of funding prerequisites for success. The results presented in this paper are based upon this approach. SPB damage simulation was used to evaluate the effects of thinning to reduce losses from beetle attack. In addition, the effect of different rotation lengths in both thinned and unthinned stands on expected loss were also examined.

EXPECTED LOSS

SPB infestation dynamics consist of two events, spot occurrence and spot spread. For purposes of this study, spot occurrence is defined as the probability of an infestation occurring in a stand. Spot spread is the number of trees killed after an infestation becomes established. Therefore, expected loss is the product of spot occurrence and spot spread. Expected loss can be expressed in terms of volume, dollar value, etc., but for the purpose of this paper, it is defined as the expected number of trees killed.

DAMAGE SIMULATION

The damage simulator used in this study is a computer program consisting of several submodels. It is used to stochastically generate expected losses for forest stands in the Piedmont. The most important components of the program are a spot growth model and a function to predict the probability of an infestation occurring. The spot growth model. is a regression equation for predicting the number of trees killed per day (Hedden and Billings 1979). The probability model is a logistic function which generates the probability of an infestation occurring per acre (Hedden, unpublished).

In this study, the program is used to simulate expected losses in planted loblolly pine stands in the Piedmont. Originally, the program was developed and validated for natural pine stands in the Gulf Coastal Plain. For more detailed information about the program, please contact the author.

Input necessary to run the program for Piedmont plantations is:

-- forest type (shortleaf or other),
-- clay content of the surface soil (less or greater than 28 percent),
-- landform (steep side slope or other),
-- radial growth in the last five years, and
-- basal area per acre (pine + hardwood).

The simulation is run 100 times for each year for which data has been input.

Output for each stand simulated is:

-- average probability of an infestation occurring per acre per year,
-- mean number of trees killed in a spot if an infestation does occur, and
-- average expected number of trees killed per acre per year.

The absolute values of expected loss generated for planted stands in the Piedmont may be biased. However, when comparisons are made between either thinning regimes or different rotation lengths, percentage differences are used. The magnitude of differences in expected loss are probably representative of changes which would actually occur.

SOURCE OF DATA

The data used in this study are from three series of .25 or .10 acre permanent plots established in young loblolly pine plantations on the Clemson Experimental Forest (Goebel et al. 1974). Trees in series I plots were planted in 1937 at spacings of 6 x 8 feet. Series II plots were planted in 1938 at a spacing of 6 x 7 feet, while series III plots were planted at 6 x 6 feet in 1940. Series I plots were thinned at ages 12, 21, 26, and 34 years. Series II plots were thinned at 13, 18, 20, 24, 33, and 41 years of age. Series III plots were thinned five times at ages 16, 20, 24, 30, and 39.

For purposes of this study, an unthinned control and a paired thinned plot were chosen from each series. The thinned plot from series I had been cut to a residual basal area per acre of 81 square feet at each thinning, while plots from series II and III were thinned to average basal areas of 84 and 104 square feet per acre, respectively. The average site index (25 year base) for series I and II plots was 51 feet. Average site index for the series III plots was 55 feet. All of the plots are located on clay surface soils with little or no slope.

SIMULATION RESULTS AND DISCUSSION

Results relating to the effect of rotation length on expected loss will be presented first, followed by the results of the effect of thinning on the reduction in the number of expected trees killed. All of the simulations began at age 10 and continued until the specified rotation age, Simulations were started at age 10 because stands younger than his are rarely attacked by the SPB.

Rotation Length Effects

In the unthinned plots, the expected number of trees killed was always lower for short rotations as compared to longer periods (Table 1). Expected loss increased while the percentage reduction in loss decreased linearly with length of the rotation.

Table 1. Expected number of trees killed per acre (ELOSS) and reduction in loss as a percentage of ELOSS for the longest rotation (PLOSS) in the unthinned plots.

Plot series	Rotation age	ELOSS (trees/acre)	PLOSS (%)
I	45	19.03	--
	40	16.21	15
	35	14.17	26
	30	10.20	46
	25	7.47	61
II	45	22.91	--
	40	18.39	20
	35	15.58	32
	30	11.39	50
	25	7.95	65
III	43	24.53	--
	40	21.17	14
	35	18.34	25
	30	13.61	44
	25	9.88	60

In all series, shortening the rotation lengths dramatically reduced expected losses. For each year that the rotation was shortened, there was approximately a three percent reduction in expected loss. In addition to the decline in expected loss, the average probability of spot occurrence also dropped.

For similar rotation lengths, expected loss was generally lowest in plot series I and highest in plot series III. Values for the series II plot were intermediate. Interestingly, these trends follow the initial planting densities closely; series I plots were planted at a density of 908 trees per acre while series II and III plots were planted at densities of 1037 and 1210 trees per acre.

Results for the thinned plots were very similar to those obtained for the unthinned plots (Table 2).

Table 2. Expected number of trees killed per acre (ELOSS) and the reduction in loss as a percentage of ELOSS for the longest rotation (PLOSS) in the thinned plots.

Plot series	Rotation age	ELOSS (trees/acre)	PLOSS (%)
I	45	13.96	--
	40	10.96	21
	34	8.80	37
	26	6.19	56
	21	4.54	67
II	46	13.79	--
	41	10.25	26
	33	7.16	48
	24	4.28	69
III	43	16.19	--
	39	13.89	14
	30	9.74	40
	24	7.32	55
	20	4.82	70

In all cases, thinned or unthinned, shortening the rotation length reduces losses from SPB attack. This reduction is due to the stand being subjected to potential infestation for fewer years, and due to a younger stand being generally more vigorous (greater radial growth) than an old stand. Very young stands also tend to have lower stand densities than comparable older unthinned stands. All of these factors together result in younger stands suffering lower levels of damage from SPB attack than older stands.

Thinning Effects

Projected expected losses on a per acre basis were always lower for the thinned plots than for the paired unthinned plots at similar ages. The probability of infestation and the number of trees killed if a spot did occur were also lower for the thinned plots. Table 3 shows the percent reduction for each of these variables at various rotation ages.

There was a greater reduction in expected loss due to thinning in plot series II than for either series I or III plots. This result is due to the greater frequency of thinning in the series II plot. This plots was thinned six times at an average interval of six years beginning at age 13. Neither of the plots in series I or III was thinned with the same intensity as series plot II.

Table 3. Percent reduction in expected loss (ELOSS), probability of infestation (PINF), and number of trees killed per infestation (TKILL) in the thinned plots when compared to the paired unthinned plots at similar ages.

Plot series	Plot age (yrs.)	Percent difference ELOSS (%)	PINF (%)	TKILL (%)
I	45	27	21	10
	40	32	23	15
	34	33	23	19
	26	22	17	8
II	46	40	25	22
	41	46	24	28
	33	48	19	35
	24	42	12	36
III	43	34	18	22
	39	32	17	21
	30	28	13	22
	24	27	9	16

In the Piedmont, management objectives associated with thinned and unthinned stands are usually different. Thinned stands are generally managed for sawtimber (large diameter stems) while unthinned stands are usually managed for pulpwood (total fiber yield). This difference usually results in a stand managed for sawtimber having a longer rotation length than an unthinned stand managed for pulpwood, assuming that both stands are planted at the same initial density and on similar sites. Therefore, comparison of thinned and unthinned stands at the same age may not be appropriate. Table 4 contrasts expected losses for the thinned and unthinned plots at various ages. When the rotation length for the thinned plots is ten years longer than for the unthinned plots, projected expected loss is almost always greater for the thinned plots. However, when the rotation age for the thinned plots is extended only five years then losses in the thinned plots are usually less than expected loss in the unthinned plots.

The figures for expected loss presented in Table 4 are expressed in number of trees killed and, therefore, do not accurately represent potential value loss. Usually the average value of a tree in a thinned stand at the end of the rotation will be greater than the value of a tree in an unthinned stand at harvest. This difference is due to trees of large diameter having greater value than small trees. Therefore, even though the expected number of trees killed may be greater in unthinned stands, the actual value loss in thinned stands may equal or exceed that in unthinned stands.

Table 4. Expected number of trees killed per acre (ELOSS) for contrasting rotation ages for thinned and unthinned plots.

Plot series	Unthinned age (yrs.)	ELOSS (trees/acre)	Thinned age (yrs.)	ELOSS (trees/acre)
I	25	7.47	30	7.48
	30	10.20	35	9.50
	35	14.17	40	11.50
II	25	7.95	30	6.20
	30	11.39	35	8.30
	35	15.58	40	10.50
III	25	9.88	35	9.74
	30	13.61	40	10.25
	35	18.34		15.00

This increase in value loss must be viewed against the total cash flow associated with a particular forest management regime. Even though the value loss may be greater in the thinned stand managed for sawtimber, the total discounted cash flow for this regime may be up to 50 percent greater than for the same initial stand if it had been managed for pulpwood. Thus, any increase in value loss due to SPB attack may be more than offset by the increase in the net present value from managing for sawtimber. However, the financial advantages of sawtimber management are primarily due to the difference in sawtimber and pulpwood stumpage prices. If the value of pulpwood stumpage increases relative to sawtimber, losses from SPB attack may make a sawtimber regime less attractive than a pulpwood regime.

Decisions on thinning should be based upon the landowner's objectives. As previously mentioned, thinning in the Piedmont is usually associated with management of sawtimber stands. The net result of thinning is normally a reduction of the rotation length over that of unthinned stands managed for the same product. Thinned loblolly pine stands will reach sawtimber size in under 35 years whereas unthinned stands require 40 to 50 years to attain the same size. Other benefits of thinning include increased growth of residual trees, improvement in product quality and early return on investment. Of these benefits, shortening the rotation length and increasing tree growth (vigor) will result in a reduction of loss due to SPB attack. Thinned stands will be exposed to attack for shorter periods of time, and they will be more vigorously growing (less susceptible to attack) during this period.

CONCLUSIONS

In order to minimize losses from SPB attack, the goal should be to maintain healthy, vigorously growing pine stands. Thinning, when properly executed, is a potential tool to accomplish this objective. Thinning, however, is not a panacea. Losses from SPB attack will occur in thinned stands. These losses will probably be concentrated in the years near the end of the rotation period; however, the magnitude of these losses will be less than for an unthinned stand being managed for the same product. Regardless of the product being managed for, shortening of the rotation length will always result in reduced losses from SPB infestation.

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IMPACT OF THINNING ON HOST SUSCEPTIBILITY[1/]

BY

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Abstract.--Changes in host condition (vigor) are due in part to thinning related disturbances. Using growth as an indicator of vigor we observed a decrease in growth which was related to the intensity of the disturbance. Thinning influences, dramatically, the environment in a positive manner for the residual stems and some pest species but in a negative manner for other pest species. Utilizing total resin flow and relative viscosity it was observed that trees basally scarred expressed a relative decrease in susceptibility to bark beetle attack. Thinning, however, provides resources for other pest and potential pest organisms in the southern forest ecosystem.

INTRODUCTION

In general, southern pine beetle (Dendroctonus frontalis Zimm.) infestations occur In slow growing, overstocked pine stands where individual tree vigor and resistance to attack are low (Hicks et al., 1980, Ku et al., 1980). Thinning is being recommended to reduce stand susceptibility to southern pine beetle attack. The rationale being that thinning will decrease competition and stress within the stand, thus increasing vigor and resistance of the individual tree. Treatments that are not cautiously applied may create conditions conducive to other pests or alter environmental factors that may offset any benefits of thinning (Belanger, 1979). Some of the post-thinning concerns in southern pine stands include Ips spp. (engraver beetles), D. terebrans (Oliv.) (black turpentine beetle), Heterobasidium annosum (Fr.) Bref. (=Fomes annosus (Fr.)Cke.), other root and stem diseases, root breakage, soil compactlon, and windthrow to mention a few. In addition, conditions might influence the population build-up of such species as the pales weevil (Hylobius pales (Herbst)) a problem in regeneration areas along with insect species capable of transmitting the pine wood nematode (Bursaphelenchus xylophilus (Steiner & Buhrer)Nickle), the causal organism of the pine wilt disease. Growth losses or production losses resulting from these factors have not been quantified for the South, but in other forest regions losses exceeding 10 percent have been attributed to thinning-caused stand and site damages (Froehlich, 1976).

In order to understand and estimate what impacts thinnings have on the stand and individual trees it will be the intent of this paper to explore: (1) hypotheses concerning host vigor/insect/thinning interactions jointly and seperately, (2) the changes in host condition (vigor) as related to thinning operations or simulated thinning disturbances, and (3) findings and a resulting conceptual view of thinning operations on pest populations.

HOST VIGOR - GROWTH

Host vigor, as measured by growth, may decline immediately following thinning. From studies on the John W. Starr Memorial Forest, Mississippi State University, Nebeker (1980 unpublished) found growth differences in relation to intensity of thinning. Hughes' (1981 unpublished) studies on

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these same plots described the amount of growth loss as a function of distance from a rut and depth of rut. Figure 1 illustrates the volume loss for 3 different rut depths. Hence, it can be concluded that the rate and duration of decreased growth is a function of may factors. The principal factors being related to the amount and intensity of site - and stand - disturbances caused by the thinning operation. Some of the main factors are the amount of soil compaction, root breakage,

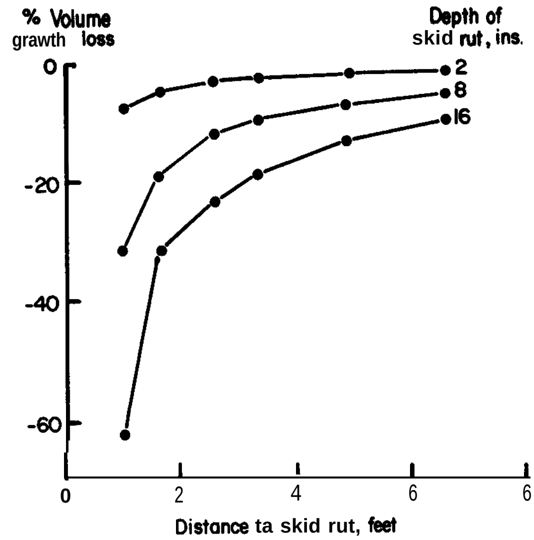

Figure 1. Growth loss in'relation to skidding - caused soil damage (rutting) on the John W. Starr Memorial Forest after Hughes (1981 unpublished).

bole scarring and damage to the residual stems that takes place at a given point in time. This concept is presented in figure 2. Here we see that if thinning takes place early in the period

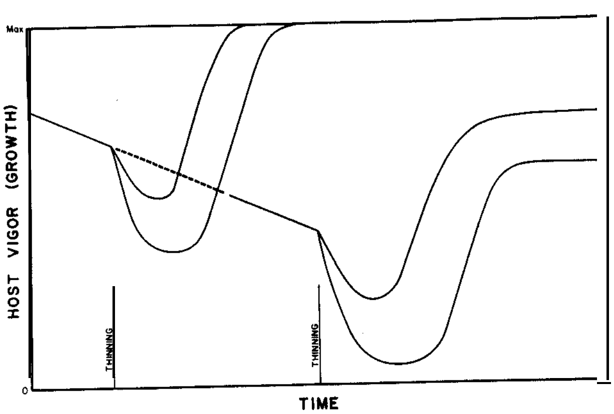

Figure 2. Conceptual view of decreasing growth as a function of time and amount of disturbance associated with thinning.

after a decreased growth rate is observed, say after crown closure, two different intensities of damage can cause different response times but trees will evenutally return to near the maximum growth rate observed prior to the decrease resulting from stand **competiton.** However, if thinning is delayed and similar amounts (intensity) of site and stand disturbances occur the growth responses are much slower (reduced even more and for a greater duration). Also, the growth rate does not return to or approach rates observed for earlier **thinnings.**

Conceptually, even though growth rates may decrease, the alteration in host- and **environmental-** conditions following thinning ultimately increases resistance to pest attack, primarily bark beetles. This concept is presented in figure 3. Here

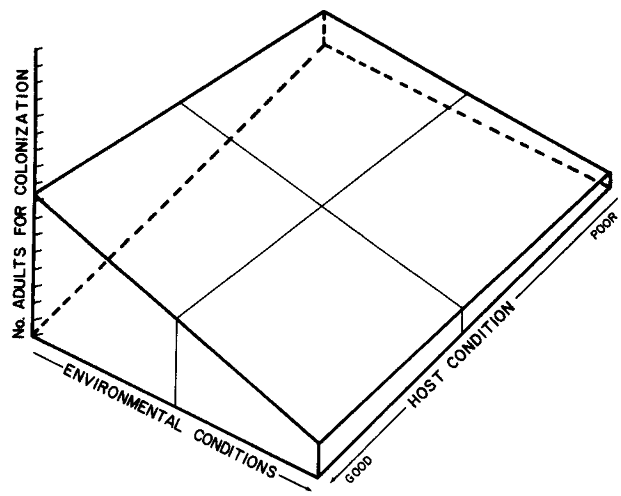

Figure 3. Conceptual view of the relationship between host- and environmental-condition and the resulting relative population required to successfully colonize a tree.

environmental conditions are considered in terms of what is favorable for bark beetle populations not from the individual tree's point of view. That is to say that after thinning the enviroment within the setting is less favorable for bark beetles, but more favorable for the residual stems because of the decrease in competition. Bark beetles, in particular the southern pine beetle, are more frequently associated with dense stands. Consequently, it takes a higher population in the area to successfully attack trees in thinned stands, where the hosts are in good condition, than in an unthinned high basal area stand where host condition is poor. Host condition, as used here, may be assessed by such characteristics as amount of resin flow for a specified time period, rate of flow and viscosity as identified by Hodges et al. (1979).

CHANGES IN HOST CONDITION AS RELATED TO THINNING DAMAGE

During 1981 we initiated several studies looking at the influence of thinning related damages to the tree, with the goal of determining if the residual stems were placed in a position of increased vulnerability and, if so, how. Hence the discussion here will be related to observations from these on-going studies and general observations from visits to numerous thinning operations throughout the south.

Let us first describe an experiment where we attempted to simulate various intensities of thinning damage in 2 loblolly pine stands on the John W. Starr Memorial Forest. The stands were thinned to basal areas of approximately 90 ft^2. Within the stands the residual stems received one of six treatments as outlined in Table 1. Trees were 11 or 14 yrs and residual stems ranged from 5 to 10 inches DBH. Basal scarring was accomplished utilizing hand knives. Root pruning was done with the aid of a Ditch Witch.

Table 1. Simulated thinning damage treatments on the John W. Starr Memorial Forest - 1982.

Treatment	Description	Number Receiving Treatment (n)
1 (Control)	Control	75
2 (R1)	Roots pruned on I side	25
3 (R2)	Roots pruned on 2 sides	25
4 (S)	Basal scar	25
5 (SR1)	2 + 4	25
6 (SR2)	3 + 4	25

Root prune = width of canopy on treatment side x 1 ft deep.
- Trench dug with a Ditch Witch 1 ft from the trees base.

Basal Scar = 1/4 bole circumference X 1.5 ft in height.

The following information was recorded for each residual stem prior to treatment and/or after: total height, height to first live limb, diameter, growth (last year, last 5 years, and last 10 years), electrical resistance, total resin flow for 8 hours, initial rate of flow, rate of ball fall (relative viscosity), oleoresin exudation pressure, and monoterpene levels. In addition stem maps were prepared to indicate the location of the various treatments and other information deemed necessary. Heights were measured with a Suunto. Growth was, determined from cores, extracted with an increment borer and measured in the laboratory under a dissecting microscope. Electrical resistance was measured with a Shigometer. Total resin flow was determined by inserting a piece of glass tubing ca. 0.5 inches (1.27 cm) into the tree, penetrating the xylem. The tubing was 9 mm outside diameter with a 2 mm inside diameter opening. Resin was allowed to flow through this tube and accummulate in a pipette for 8 hrs. Relative viscosity was determined by dropping a perfectly spherical aluminum ball, 0.0625 mm, in diameter into the resin contained in the collecting pipette. Since the measurements being compared were made within a few days of each other and under similar environmental conditions, corrections for temperature were not made for these relative measures. Oleoresin exudation pressure was determined by inserting manometers into the tree through at least two annual rings. The manometers were made from glass tubing 2.5 mm outside diameter, 1 mm inside diameter and 150 mm in lenght. The tubing was sealed on one end.

In a previous study (Hodges et al., 1979) it was concluded that trees more resistant to bark beetle attack had: (1) greater total flow for a given time period, (2) greater viscosity, and (3) a higher rate of crystallization. Due to changes in methodology in this experiment the rate of crystallization was not determined. However, the other two were, including chemical analysis of the total monoterpene (mg/100 mg) in the oleoresin. Results of this work are presented in Tables 2-5.

Table 2. Mean monoterpene content (mg/100mg oleoresin) with respect to treatment during 1982.

Treatment	April	May	July
Control	32.33	30.57	30.32
R1	31.32	29.45	31.22
R2	31.92	30.78	32.88
S	30.04	29.67	35.20
SR1	32.71	33.84	31.92
SR2	33.43	30.55	33.55

April = Pretreatment
May-July = Posttreatment

Table 3. Results of analysis of variance considering variables potentially useful in identifying host condition-vigor as a function of month and treatment 1982.

Variable	Factor	Significance
Oleoresin Exudation Pressure	Month	**
	Treatment	N. S.
Electrical Resistance	Month	**
	Treatment	N. S.
Resin Flow Rate (Max.)	Month	*
	Treatment	N. S.
Total Flow	Month	**
	Treatment	**
Relative Viscosity	Month	**
	Treatment	*

** = 0.01 level
* = 0.05 level
N. S. = non significant

The total monoterpene content did not change with respect to time nor treatment (Table 2). The greatest increase, however, being noted in trees receiving only the basal scarring. Of the other potential vigor indicators we see in Table 3 that only total flow and relative viscosity are influenced by treatment. This was not totally unexpected because of previous experience. The next step was to determine in what direction, i.e. greater flow or less, greater relative viscosity or less, the change occurred in relation to the controls. Hence multiple range tests were conducted. The results are presented in Tables 4 and 5. With respect to total flow there were no differences prior to treatment (April) among the trees assigned to the various treatments. Immediately following treatment (May) the only significant difference was between the controls and those scarred and root pruned on one side. During July significant differences were observed between the control and those which were basally scarred (Table 4). This could be a direct response to the wounding resulting in increased resin production.

Table 4. Mean total resin flow (ml/8 hrs.) per treatment - 1982.

Treatment	April	May	July
Control	1.92	1.00	2.51
RI	1.86	1.38	3.13
R2	1.96	1.12	2.60
S	2.47	1.54	5.10 [illegible]
[illegible]	2.78	2.42 **	5.09 **
SR2	1.96	1.40	4.78 *

April = Pretreatment
May-July = Posttreatment

Relative viscosity was not significantly different between treatments during April (pre-treatment) and May (immediately following treatment). However significant differences between the scarring treatment, scarring. plus root pruning on two sides and the controls were evident during July (Table 5). At present no explanation is offered because the monoterpene analysis is incomplete. As noted in Table 2 no differences in total oleoresin monoterpenes were evident.

Table 5. Mean relative viscosity (seconds/mm) of loblolly pine resin - 1982.

Treatment	April	May	July
Control	1.142	1.282	1.847
Rl	1.155	1.421	2.021
R2	1.287	1.047	2.352
S	1.286	1.730	3.281 **
SRI	1.254	2.158	2.641
SR2	1.600	2.047	3.182 **

April = Pretreatment
May-July = Posttreatment

The increases in total flow and relative viscosity are opposite what was expected, based on Hodges et al. (1979) results for moisture stressed trees. In the latter case decreases were observed. Traditionally it has been assumed that stressing a tree will decrease its resistance (vigor) and ultimately result in greater susceptibility to pest attack. From the above what might we suggest concerning host vigor as it relates to thinning related disturbances? It appears from this study that host vigor, using the measure of total flow and relative viscosity, is increased as a result of thinning related damage. This concept is presented in figure 4. The increased resistance may be short lived and dependent on the intensity of the response to the level of disturbance. The level of response, changes in total flow and relative viscosity appear inversely related to the relative growth response as presented in figures 1 and 2 and opposite in response to those resulting from water stress. It suggests that the residual damaged stems are more vigorous and more resistant to attack than undamaged residual stems. However, these damaged trees may be more susceptible to stressful environmental conditions, which were not encountered in the study, and under such conditions may not fare as well as the undamaged trees.

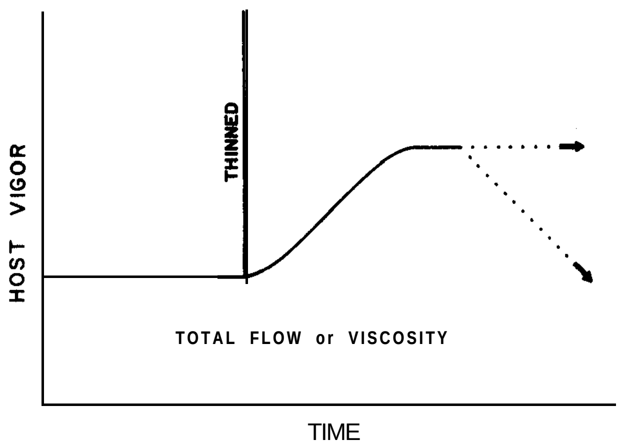

Figure 4. Relative changes in host vigor, using total resin flow and relative viscosity, following thinning related disturbances. The direction and duration of this response is not known and indicated by the dotted lines and arrows.

RESOURCE AVAILABILITY AND PEST RELATED MORTALITY

Conceptually the relationship between resources and mortality due to Ips spp. and pine wilt disease is presented in figure 5. This is a result of some 13 months of observation following precommercially-, commercially- and experimental plot-thinnings. Prior to thinning, the resource frequently utilized by bark beetles, in particular Ips spp. is somewhat constant but as the stand begins to age the resource begins to increase through various types of natural damage, i.e. the stand begins to break up. As this happens additional reproductive habitat is provided for Ips spp. and those species of insects carrying the pine wood nematode. Once the decision to thin is made and thinning takes place the resource for these species begins to increase exponentially, leveling once the maximum production of the thinning crew is reached. Assuming the same level of production is maintained, the amount of resource for the various mortality agents will remain somewhat constant. Since the slash material is suitable for Ips spp. reproduction as well as for the species carrying the pinewood nematode, the mortality due to Ips decreases, however, the mortality due to pine wilt disease increases as shown in figure 5. The primary reason for this trend is that the Ips population is being absorbed by the slash. But the adults of insects carrying the pine wood nematode feed on the tissues of the residual stems and subsequently the pine wood nematode is introduced into the residual stems. The nematode reproduces rapidly, taking only approximately 4 days to complete a generation. From our observations 72% of the dead trees with no bark beetle attacks were infected and cause of death was attributed to the pine wilt disease. Prior to thinning no trees were observed with the pine wilt disease. Hence the relative level of mortality due to this disease in the thinned setting is higher than was observed prior to thinning.

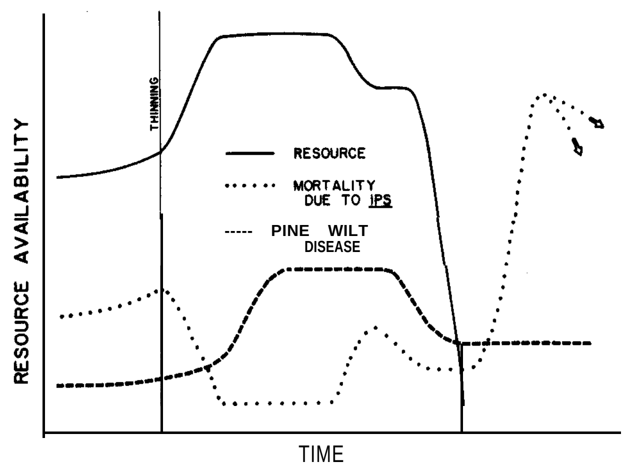

Figure 5. Conceptual relationship between resource availability and susequent mortality to the residual stand following thinning.

As thinning levels decrease and resource availability decreases the mortality due to Ips spp., begins to increase. Given a situation where thinning ceases abruptly in an area as depicted in figure 5 mortality to the residual stems would increase dramatically. This is true for a number of bark beetle species where windthrow and tree parts, i.e. slash, serve as the preferred habitat to reproduce in. When the preferred resource is no longer sufficiently available to absorb the population then the residual standing stems become focal points of colonization. The distribution of the slash also has an important bearing on the amount of mortality to the residual stems. We have observed that when the tops are piled near a residual stem, verses being scattered, there is a higher probability that those stems will be attacked by the emerging Ips population. An interesting note in our observations is that those trees that were basally scarred were not attacked by Ips. Mortality due to Ips occurred only in non-scarred stems. The black turpentine beetle and the coneworm (Dioryctria spp.) were observed attacking the scarred trees but no mortality has been recorded to date.

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SALVAGE CUTTING IN SOUTHERN PINE FORESTS[1/]

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Abstract.--Fusiform rust and the southern pine beetle are the most widespread and destructive forest pests in the southern pine forests. Salvage cutting is a means of reducing losses this insect and disease in merchantable stands. Establishing treatment priorities, scheduling, marking guidelines, and harvesting systems for salvage operations are discussed in relation to stand characteristics and the extent of damage. Stand disturbance and related pest problems are the risks associated with salvage cutting.

A recent survey of forest industries in the South ranked fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*) and the southern pine beetle (*Dendroctonus frontalis* Zimm. - SPB) as the two greatest pest problems in their operations. Annual losses to these agents total more than $200 million. Pest management strategies are available to reduce losses from this insect and disease throughout the life'of the stand. Control options decrease, however, as stands mature, competition increases, and growth declines.

Salvage cutting is a means of reducing losses from insects and diseases in merchantable stands. Yet, many forest managers are not familiar with the concept or implementation of this silvicultural practice. This paper (1) describes the development of guidelines for salvage of trees severely infected with fusiform rust in pine plantations, (2) summarizes established guidelines for the salvage removal of SPB-infested material in pulpwood and sawtimber stands, and (3) defines the role of salvage cutting in the management of southern forests.

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SALVAGE IN RUST-INFECTED PLANTATIONS

Salvage cutting has often been proposed for reducing losses to fusiform rust in pine plantations (Powers *et al.* 1974; Belcher *et al.* 1977); Schmidt and Klapproth 1982). A large-scale study is being conducted in South Carolina, Georgia, and Alabama to develop guidelines for the proper selection, marking, and harvesting of damaged loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm. var. *elliottii*) pines in plantations being managed on 22-25 year rotations.[3/] The primary management objective is high yields of wood fiber.

In 1981, eight slash pine plantations were selected for treatment. Infected trees were removed from portions of the plantations; the remaining portions have been left as controls. Four 1/4-acre fixed plots were established in the treated and untreated areas of each plantation to assess the effect of salvage cutting on total production. A wide range of stand, site, and pest conditions are being examined.

Stand considerations.--Several factors must be considered in selecting stands for salvage cutting. The most obvious and important is the incidence of rust. The cooperators in this study are salvage cutting in plantation8 where the incidence of stem galls ranges from 30 to 60 percent. Less than 30 percent infection would be too few stems for profitable harvest; stands with more than 60 percent would be clearcut and regenerated.

3/ Belanger, R. P., T. Miller, R. S. Webb, and J. F. Godbee. Forest management strategies for reducing beetle- and pathogen-caused losses in planted stands: The salvage cutting of trees infected with fusiform rust. Research funded by the Integrated Pest Management RD&A Program for Bark Beetles of Southern Pines.

Age of the study plantations at the time of salvage ranged from 14 to 20 years old. Individual trees and total volume in plantations younger than 14 years are usually too small for commercial cutting. There is little biological or economic advantage in salvage cutting rust-infected trees close to rotation age.

Volumes ranged from 10 to 40 cords/acre prior to treatment; number of live trees from 400 to 550 stems/acre. Pretreatment assessments indicated that at least 4 cords/acre had to be removed to satisfy the cost/benefit requirements of harvesting.

Tree considerations.--The success of salvage cutting in rust-infected plantations is based on anticipating mortality. Three risk classes, based on number, location and condition (extent and severity of gall cankering) of rust galls on the main stem, are being evaluated.

Low risk. Trees likely to survive through rotation; either rust-free or with galls of a size and condition that will not affect survival.

Moderate risk. Trees with one or more galls whose location, size (generally < 50 percent of stem circumference) and condition makes survival to rotation age questionable.

High risk. Trees likely to die before rotation; one or more galls generally encircling ≤ 50 percent of the circumference of the main stem; severe stem cankers are common.

These risk classes are the primary basis for marking and removal. Tree size and spacing are not major considerations in the selection process. All high risk trees are marked; low risk trees are not marked. Moderate risk trees may or may not be removed depending on management objectives and restrictions specific to individual plantations. Several field foresters have been trained in this system. They are able to identify the three classes quickly and accurately.

Harvesting systems.--Another objective of the study is to determine the kinds of harvesting systems best suited for salvage cutting. We are comparing costs and benefits of tree-length and shortwood removal. Tree-length logging is being done by company harvesting crews in heavily mechanized operations. Shortwood removals are being done by contract loggers with labor-intensive systems.

Cutting operations are being conducted in different geographic regions and stand conditions. Initial spacing, soil characteristics, topography, and processing requirements all have a bearing on the costs, production, and suitability of the different harvesting systems.

Scheduling.--Salvage cutting was conducted during the spring, summer and fall of 1981. Scheduling was strongly dependent on the availability of logging crews and local markets.

Associated pest problems.--Forest managers are cautious about intermediate cuttings without knowing the impact on bark beetles, root diseases and other pest problems. A major objective of this study is to identify and quantify these risks. Logging damage and associated insect activity were assessed during the winter of 1981-1982.

Preliminary results.--Eight slash pine plantations have been salvage cut to date. Harvesting operations removed an average of 10.9 cords/acre (Table 1). Basal area was reduced from an average of 96 $ft.^2$/acre to 61 $ft.^2$/acre (Table 2). Residual stocking averaged 276 stems/acre (Table 3). Most of the trees removed were from the high and moderate risk classes.

Table I.--Salvage cutting affected the average volume distribution of fusiform-rust risk classes in eight slash pine plantations

Fusiform-rust risk class	Volume		
	Pretreatment	Salvaged	Residual
	Cords/acre 1/		
Low	20.0	2.7	17.3
Moderate	5.5	4.0	1.5
High	4.9	4.2	0.7
Total	30.4	10.9	19.5

1/ Cords = $ft.^3$/78

Table 2.--Salvage cutting affected the average basal area distribution of fusiform-rust risk classes in eight slash pine plantations

Fusiform-rust risk class	Basal area		
	Pretreatment	Salvaged	Residual
	$Ft.^2$/acre		
Low	61.6	8.6	53.0
Moderate	17.8	12.5	5.3
High	16.6	13.8	2.8
Total	96.0	34.9	61.1

Table 3.--Salvage cutting affected the average number of trees/acre in each fusiform-rust risk class in eight slash pine plantations

Fusiform-rust risk class	Live trees/acre Pretreatment	Salvaged	Residual
	---Number---		
Low	256	37	219
Moderate	86	55	31
High	100	74	26
Total	442	166	276

Salvage cutting removed 74 percent of the stems with severe rust infections. These high-risk trees represented 33 percent of the total volume harvested. Residual high-risk trees--only 3 percent of the total stand--were too small to remove efficiently (Tables 4 and 5).

Table 4.--Salvage cutting affected the average diameters of trees in fusiform-rust risk classes in eight slash pine plantations

Fueiform-rust risk class	D.b.h. Pretreatment	Salvaged	Residual
	---Inches---		
Low	6.4	6.3	6.4
Moderate	5.8	6.2	5.2
High	5.2	5.6	4.0

Table S.--Salvage cutting'affected the average heights of trees in fusiform-rust risk classes in eight slash pine plantations

Fusif orm-rus t risk class	Total height Pretreatment	Salvaged	Residual
	---Feet---		
Low	50.3	50.9	50.2
Moderate	46.8	48.2	43.9
High	41.5	43.8	35.5

Salvage cutting increased the proportion of healthy and low-risk trees in the study plantations from 58 *to* 79 percent. Quality and general vigor of the residual stand were significantly improved. Approximately 37 low-risk trees/acre were removed to provide access through the stand by harvesting equipment. These trees represented 25 percent of the total volume removed. Salvage cutting did not affect the average diameter or total height of the residual low-risk trees since they were selected by chance rather than by choice.

Moderate-risk trees were left at the discretion of the markers. Many large trees with small infections were left because of their potential value as sawtimber; small trees in the low to moderate risk classes were removed to reduce the number of slow-growing trees that would be suceptible to insect attack. Removal of these moderate-risk trees can also improve spacing in the residual stand. Moderate-risk trees represented 33 percent of the stems removed and 37 percent of the total volume salvaged from the study plantations.

An average of 18 trees/acre--6.6 percent of the residual stand--were damaged during salvage removal. Tree-length logging accounted for 55 percent of the total damage while the remaining 45 percent resulted from shortwood operations. Most of the damage (65 percent) occurred as wounding or scarring on the main stem. The remaining injuries were broken live branches or severe bending of small trees caused by felling.

Only 12 percent of the damaged trees were attacked by *Ips* and black turpentine (*Dendroctonus terebrans* Oliv.-BTB) beetles. Attacks seemed to be related to the number and size of stem wounds (Table 6). Damaged trees with insect activity had more wounds per tree, more surface area per wound, and more wound area per tree than did damaged trees without insect activity. *Ips* and BTB activity was greater in the treated portions of the plantations than in the control areas (Table 7). No mortality has occurred in the study plantations to date as a result of insect activity following logging.

Dioryctria amatella **(Hulst),** the southern coneworm, is associated with active rust galls where the larvae feed and grow ***over*** winter (Coulson and Franklin 1970). This insect is not a problem pest in plantations, but can cause serious losses of cones and seeds in seed orchards. Removal of the rust-infested trees significantly reduced the incidence of ***D. amatetla.***

Prior to treatment, the root systems of 744 trees were excavated and inspected for resinosus or decay associated with diseases such as annosus root rot (*Heterobasidion* annosum [Fr.] Bref. A total of 31 trees had some roots with symptoms of disease. Samples of these roots were cultured to determine specific pathogens. Only ***H. annosum*** and ***Inonotus circinatus*** were recovered from the symptomatic root tissue. The frequency of root disease fungi were:

Heterobasidion annosum	1 tree
Inonotus circinatus	3 trees

Mushroom root rot (caused by *Clitocybe tabescens* [Scop] Bres.) was also noted (visual inspection--no culture) on three trees. The occurrence and recovery of all root decay fungi from these excavated trees were low, but this was expected since the plantations had not been previously thinned.

Continuing research.--In 1982, a similar effort went into the selection and treatment of rust-infected loblolly pine plantations. The slash pine data will continue to be strengthened. Detailed rust profiles are being developed for plantations of both species. We will continue to monitor the plantations for insect and disease activity.

Table 6.--Relationships between logging damage and associated insect activity following the salvage cutting of fusiform-rust-infested trees in eight slash pine plantations

	Trees with stem wounds	Stem wounds per	Surface area per wound	Surface area per tree
	---------Number----------		------------Ft.^{2}------------	
Damaged trees with insects	18	1.7	0.25	0.42
Damaged trees without insects	77	1.2	0.13	0.15

Table 7.--Number of trees attacked by different insects in treated and untreated portions of eight slash pine plantations

Insect	Portion of study plantations: Salvaged	Control
	---------Number of infested trees-------	
Black turpentine beetle	27	7
Ips spp.	1	
Dioryctria amatella	37	128
Unknown	3	

GUIDELINES FOR SALVAGE OF SPB-INFESTED TREES

The southern pine beetle occurs across all geographic regions of the South. Frequency and severity of SPB attacks are most serious in mature, densely stocked, slow-growing pine stands. Insect activity is increased even more when these etands are disturbed (e.g. lightning, logging damage). Rapid salvage of infestations is a means of recovering losses and reducing beetle populations (Morris and Copony 1974, Billings and Pase 1979).

SPB infestations are normally located from aerial observations (Billings and Doggett 1980) and ground checked to determine the need and priority for treatment (Billings and Paee 1980). High-priority spots--those with the greatest number of actively-infested trees--should be marked for treatment first (Swain and Remion 1981).

Field crews should be instructed to mark and remove a buffer strip of uninfested trees around the active head of each infestation. This practice stops spot growth and is a precaution against leaving undetected infested treee. Buffer stripe can range from 10 to 100 feet, depending on the stage of brood development, stand density, and the number of newly attacked and brood-producing trees (Billings and Pase 1980). Wide buffer strips are recommended for high-priority spots whereas smaller buffer strips are adequate for medium- and low-priority spots. Harvesting should etart as soon as possible after marking. The order in which trees are removed depends on the season (Swain and Remion 1981). During May to October, buffer zone trees should be removed first, then freshly attacked trees, and finally the trees with living brood. This sequence reduces spot spread. Between November and April, trees with older brood should be removed first, then newly attacked trees, and finally the trees in the buffer zone. This sequence reduces spot proliferation.

Salvage cutting is an effective and economical method of treating large SPB infestations. More than 2.8 million cords and 1 billion board feet of SPB-killed and infested timber were harvested in the South during beetle outbreaks between 1970 and 1976 (Price and Doggett 1978). This material was used profitably for a wide range of products (Levi 1981).

THE ROLE OF SALVAGE CUTTING IN SOUTHERN FORESTS

Damage from insects and diseases occurs almost continuously in southern forests. Environmental conditions favor several major pests: SPB, fusiform rust, littleleaf disease (*Phytophthora* Rands), and annosus root rot. Some stands damaged by these pests are suitable for salvage cutting while others are not. Choice of action depends on the extent of damage, management objectives, and benefits that result from treatment.

Excellent guidelines have been developed for salvage of trees damaged by the SPB. Harvesting can range from light partial cutting to clear-cutting depending on the size and number of infestations. Guidelines are not yet available for applying salvage cutting in stands infected by fusiform rust. A major problem is the inability to predict losses based on the severity of rust in merchantable pine plantations. The primary purpose of our current research is to anticipate and prevent these losses.

Salvage of mortality caused by root diseases depends on the rate at which damage occurs. Losses from littleleaf disease and H. *annosum* usually occur slowly over time and are widely scattered throughout the stand. Immediate losses are likely to be minimal; frequent salvage cutting is generally impractical. Stands with severe infections of littleleaf disease or annosus root rot should be clearcut.

The need, practically, and application of salvage cutting depends on:

* Forest management objectives
* Extent of the pest problem
* *Severity* of the pest problem
* Type of damage
* Value of the timber
* Volume of the timber
* Accessibility of the stand
* Market conditions
* Availability of harvesting crews
* Pest management considerations

Salvage cutting should be considered as a means of reducing losses from insects and diseases <u>only</u> when it is biologically and economically feasible to ao so.

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FREEZE- AND KILN-DRYING OF SLASH PINE CONES AND SEEDS[1/]

James P. Barnett[2/]

Abstract.--Seed yields were greater from freeze-dried than kiln-dried cones, possibly due to a more complete drying. Whether seeds were further dried by kiln- or freeze-drying methods had no effect on the number of germinating seeds but did influence the speed of germination. After storage for 20 months 'at 72°F, seeds from freeze-dried cones had lower viability than those from kilned cones, regardless of the method of seed drying. Seeds from freeze-dried cones that were further dried by freeze drying had the lowest viability. Apparently the very rapid desiccation damages the seeds. The moisture contents of the kiln- and freeze-dried seeds averaged 5.4 and 2.2 percent, respectively, regardless of cone drying method, Probably because moisture levels were so low, viability of the seeds from kilned cones remained constant over the 20-month period at room temperature. Freeze-drying to reduce seed moisture for long-term storage is feasible, but only if the seeds are partially dried by some other technique; otherwise seed damage can occur.

INTRODUCTION

One of the major factors influencing seed longevity is seed moisture content. At normal storage temperatures (20° to 35°F) seed moisture contents greater than about 10 percent cause wre rapid decreases in viability. The general recommendations for storing southern pine seeds are to dry them to a moisture content of 10 percent or less (Barnett and McLemore 1970). Harrington (1973) has noted that with many agronomic seeds stored within the range of 5 to 14 percent moisture content, each 1 percent increase halved the life of seeds.

Pine seeds are not usually dried below a moisture content of 6 to 8 percent. Theoretically, drying to 1 or 2 percent moisture should maximize the length of seed storage, but it is difficult to lower moisture to these levels by conventional drying techniques without damaging the seed. Perhaps for this reason, Roberts (1972) suggests that decreasing moisture contents below 5 or 6 percent may not increase seed storability.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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Vacuum drying is especially well adapted to drying seeds to a very low moisture content. Vacuum drying is similar to drying with dehumidified air. In recent years, refrigeration has been combined with vacuum drying in what is termed freeze-drying. Refrigeration is used to condense moisture from the air and lower its vapor pressure. Although the material being dried is normally frozen, freezing is not necessary if the seeds are kept outside of the condensing chamber. The moisture rewved is continuously frozen in the condensing chamber, maintaining a steep moisture gradient.

Early results indicated that freeze-drying could improve the storage of vegetable seeds. Moisture contents can be lowered to levels that heretofore could not be reached with heat drying without seed injury (Woodstock 1975, Woodstock, et al 1976). Freeze-drying has also been tried successfully with spruce seeds (Suber et al 1973), and preliminary tests with southern pine seeds have shown that moisture levels can be reduced to 2 percent or less without apparent injury to the seed (Bamett 1979). However, the effects of these low seed moisture contents on storability have not been evaluated.

In this study, freeze-drying was compared with conventional kilning techniques as a means of cone processing and as a method of lowering seed moisture so that seed longevity can be increased.

METHODS

Freeze-drying and kiln-drying techniques were used to extract seeds from cone collections from three individual slash pine trees. The collections were made on September 24, 1979. Seven cones for each of three replications per individual tree were processed in a small gas-fired kiln at temperatures of about 105°F and in a laboratory freeze dryer where the cones were kept at slightly below ambient temperatures. Seed yields per cone was determined upon the completion of cone opening. After extraction was completed, seeds were again dried by either kiln- or freeze-drying methods to further reduce seed moisture contents. Seed moisture levels were determined prior to initial germination tests and storage. Germination tests, conducted for 30 days, were run with unstratified seeds before and after storage. Czabator's (1962) germination values, which reflect both speed and completeness of germination, and percent of germination were computed. The 0.05 level was used as the significance level in the ANOV analyses of the data.

Seeds from each treatment replication were sealed in separate polyethylene bags to maintain the initial moisture levels during the 20 months of storage at 72°F. Seeds were stored at room temperature (72°F) to hasten seed deterioration and accentuate treatment differences. Normally seeds would be stored at subfreezing temperatures.

RESULTS AND DISCUSSION

Cone Drying

Whether slash pine cones were extracted by conventional kilning or by freeze-drying techniques had no effect on initial germination (table 1). However, significantly greater seed yields were obtained from freeze-dried than kilned cones, amounting to an 8 percent increase in yield. The better yields probably reflect the faster drying and lower moisture contents of cones that were freeze dried.

Although initial germination was not affected by cone drying technique, germination values, which in this case reflect differences in speed of germination, were reduced by freeze drying (table 1). There were significant differences in all measured parameters due to variation among the individual-tree sources.

Table 1.--Slash pine seed yield, moisture content, and germination summary by drying method, initially and after storage for 20 months at 72°F

Drying method: Cones	Drying method: Seed	Tree number	Seed yield	Initial characteristic&: Moisture content	Initial: Germination	Initial: GV[2]	20-month characteristics: Germination	20-month: GV
			#/cone	-Percent-	--Percent--		--Percent--	
Kiln	Kiln	1	117[3]	5.2	99.7	55.17	99.3	45.11
		2	122	5.4	99.8	50.69	98.7	41.48
		3	141	5.6	97.5	39.87	96.0	24.56
		Mean	127 b[4]	5.4 a	99.0 a	48.58 a	98.0 a	37.05 a
Kiln	Freeze-dry	1	119	2.2	99.7	49.91	99.2	36.88
		2	118	1.8	99.0	48.82	96.0	24.95
		3		2.7	95.0	37.67	94.0	24.57
		Mean	128 b	2.2 b	97.9 a	45.47 a	96.4 a	28.80 ab
Freeze-dry	Kiln	1	129	5.4	98.2	36.37	91.0	24.50
		2	138	5.5	98.8	21.12	87.2	17.54
		3	150	5.6	96.7	26.17	85.2	18.37
		Mean	139 a	5.5 a	97.9 a	31.22 b	87.8 b	20.14 b
Freeze-dry	Freeze-dry	1	122	2.3	96.5	32.36	75.7	15.14
		2	140	1.2	99.2	26.91	21.2	1.16
		3	144	3.0	89.5	14.20	39.3	2.76
		Mean	135 a	2.2 b	95.1 a	24.49 b	45.4 c	6.35 c

1/ After drying cones and further drying of seeds with treatments.

2/ GV's are germination values which reflect both seed and completeness of germination (Czabator 1962).

/Average from 7 cones per tree.

4/ Means within columns, followed by the same letter are not significantly different at the 0.05 level.

After 20 months of 72°F temperatures, germination of kilned seeds from kilned cones had dropped only an average of 1 percentage point, whereas kilned seeds from freeze-dried cones dropped 10 percentage points (table 1)

Seed Drying

After the seeds were extracted from the cones, the seeds were further dried for storage by either kiln- or freeze-drying methods. The final seed moisture contents obtained by kilning averaged 5.4 percent compared to 2.2 percent for freeze drying (table 1). Kilning normally results in about a 10 percent moisture level. The low moisture level for kiln-drying is probably why the viability of these seeds stayed essentially the same over the 20-month period at room temperature.

Seeds from freeze-dried cones were adversely affected by both drying methods (table 1). Seeds that were freeze-dried following cone opening by freeze-drying were almost unsuitable for use following 20 months at room temperature. Why was germination so adversely affected by this treatment? No conclusive answers are available, but rapid desiccation from high to low moisture contents is known to reduce seed quality (Copeland 1976). Such excessive drying rates may cause stress cracks in the seed because of unequal drying throughout the seed.

CONCLUSIONS

Results of these tests indicate that alternative drying methods, such as freeze-drying, can be used to extract seeds from pine cones as effectively as conventional kilning. Freeze-drying should not be used to quickly reduce seed moisture contents from high levels to extremely low levels, as damage can occur that will reduce seed quality after storage. It still may be feasible to lower seed moisture contents to unusually low levels by freeze-drying and thus increase seed longevity. Freeze-drying techniques will also reduce time of drying 75 percent or more. The kiln extracted and dried seeds in this study had a moisture content of 5.4 percent, which is considerably below the levels usually obtained, and viability was retained exceptionally well following nearly 2 years at room temperatures. Thus low moisture contents can increase the time seeds can be stored and freeze-drying is one means of drying seeds to unusually low levels. However, seeds should be partially dried by some other method so that injury can be reduced.

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SWEETGUM SEEDLING ROOT STARCH CONTENT AS AN INDICATOR OF DORMANCY[1]

Robert W. Rose, Jr., and M Monica McGregor[2]

Abstract.--Sweetgum seedlings grown in Westvaco's coastal South Carolina nursery accumulated varying levels of root starch as they went dormant in the fall. Seedlings which tended to retain their leaves longer accumulated the least amount of starch prior to leaf fall in late November. All of the seedlings exhibited a dramatic increase in root starch between September and October. However, each plot of seedlings tended to reach a peak in starch content in different months. A sharp rise in starch content late in the growing season (October) may indicate that the dormancy mechanisms have been set in motion. The magnitude of the starch increase may not be as important as the beginning starch level and the month in which the starch content peaks. Knowing the level of the starch peak and when it occurs may give some indication of when to lift for optimum storage and future growth.

INTRODUCTION

The accumulation of nutrients, carbohydrates, proteins, and other compounds has interested those studying dormancy and seedling quality for a number of years (Leaf et al. 1978). Several researchers have linked dormancy and food reserves to seedling outplanting survival and growth (Farmer 1975, Gilmore 1961, Hellmers 1979, Kreuger 1967). Nelson and Dickson (1981) found that carbohydrate was stored as starch in the initial stages of dormancy induction in cottonwood stems; it was later converted to soluble sugars under cold conditions.

Dormancy. induction occurs primarily as a function of temperature, day-length, soil fertility, plant moisture stress and/or plant injury such as top pruning or undercutting. Temperature and day-length are beyond the control of the nurseryman. Plant moisture stress can be controlled if extremes in seasonal rainfall are not a problem. Soil fertility can be controlled to a point, but depends on soil type, rainfall and irrigation requirements. Only top pruning and undercutting can be directly controlled, but these techniques must be carefully timed to ensure an adequate recovery from the injury.

Timing is critical if the nurseryman is to condition the seedlings to survive and grow well after outplanting. In a previous study dormant sweetgum seedlings tested for starch prior to lifting in January were found to have a narrow range of root percent starch. The question arose as to how much starch sweetgum could be expected to accumulate prior to dormancy in coastal South Carolina. When &es the process begin? How great is the variation? How might this information be used to time nursery cultural practices such as nitrogen fertilization and time of lifting?

The experiment reported here was designed to obtain baseline data on starch accumulation in sweetgum roots as it might relate to dormancy. A plot containing typical production seedlings was added for comparison purposes.

The purpose of this study was to test for periodic changes during the fall months in root starch content in nursery-grown sweetgum seedlings.

1/ Paper presented at Second Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

2/ The authors are Forest Regeneration Scientist and Laboratory Technician, Forest Science Laboratory/Productivity Group, Westvaco Corporation, Summerville, S.C.

PROCEDURE

The study was located at Westvaco's Jericho Nursery in Ravenel, South Carolina. Figure 1 shows the layout of the experiment. Each of the seven plots was sown by hand in April 1981 at a fixed density of twelve seedlings per square foot. The seed was a southern Illinois source. Five of the plots were selected at random for use in this study. Each plot was four feet wide by eight feet long. Soil fertility at the beginning of the experiment was good with a pH of 5.45. The pounds per acre in the soil of P, Ca, Mg and K were 116, 954, 187, and 154, respectively. Soil organic matter' was approximately 1% prior to the addition of three inches of composted sawdust mixed into the top six to eight inches of soil. This raised the organic matter content to 8.6% in plots l-5. The seedlings were fertilized with Folian™ 1/ at a rate of 25 lbs. of nitrogen per acre on June 26, July 17, August 10, and August 21. Seedling growth was not proceeding well in early August due to high soil moisture and possible nutrient leaching, so potassium nitrate, ammonium nitrate, and triple superphosphate were added to each plot on August 12, 1981. The amount of N, P, and K added to each plot was equivalent to 50, 20 and 75 lbs. per acre, respectively.

Within each main plot a smaller subplot containing nine rows of seedlings was established in early August. The nine rows of seedlings were comprised of four sample rows and five buffer rows. A buffer of two seedlings was left on the edge of the beds. Each row contained eight seedlings. In early August a 4- x 20-foot area was marked off in a nearby production seedbed of the same seed source for use in this study. The production seedlings received no special organic or fertilizer treatments. Thirty-two seedlings within the production plot were randomly selected and tagged for harvesting at a later date.

Harvest Method.--One entire row of seedlings was harvested at random from each plot on September 24, October 27, November 19, and December 21, 1981. Eight seedlings were randomly selected from the production plot on the same dates. Four additional seedlings were harvested near each plot on March 18, 1982. Height and caliper measurements were taken each month on the seedlings to be harvested and those which remained from August through December.

The leaves from each seedling to be harvested were removed and placed in a paper bag. The seedlings were lifted and their roots were carefully washed with water. After cleaning the sampled seedlings were bundled together and their root systems placed in a two-quart plastic bag. The bundle was then frozen solid in a cooler containing dry ice. After freezing, the seedlings were taken immediately to the lab where they were defrosted. Each seedling was divided into stem, tap root, and lateral roots. Fresh weight of leaves, stem, and roots were taken. Each component was then dried for 48 hours at 60-70°C in an incubating oven to determine dry weight. The leaves were analyzed for N, P, K, Ca and Mg by Westvaco's Soils/Analytical Group. The individual tap and lateral roots of each seedling were tightly sealed in plastic freezer storage bags for future starch analysis. Tap and lateral roots from seedlings harvested in September, October, and November were combined prior to analysis.

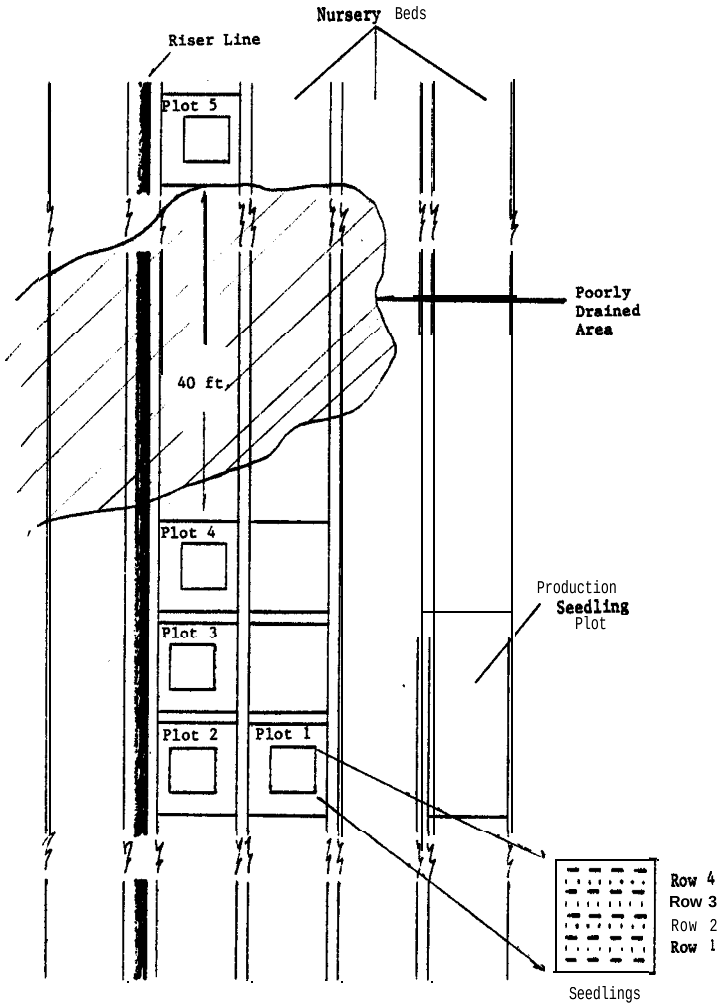

Figure 1.--Nursery layout of experiment and diagram of plot with locations of harvested rows. (Row 1 contained seedlings l-8; Row 2 9-16; Row 3 17-24; Row 4 25-32)

1/ Folian™ is an N, P, K, S, Fe liquid fertilizer, Starch Analysis.--Preparation for analysis involved chopping and grinding the roots to pass through a 40u sieve. The ground sample was placed in a tightly capped specimen vial and refrozen. At the time of testing, 100mg of ground sample were placed into a preweighed test tube, dried for one hour at 100°C, and weighed to determine its dry weight. Percent starch was based on root dry weight. The starch determination technique was 'that described by Haissig and Dickson (1979). Briefly, samples were extracted with a methanol:chloroform:water mixture to remove soluble sugars, heated in an oven to boil off the chloroform, gelantinized for 30 minutes in a boiling water bath, and incubated at 40°C for 48 hours in the presence of two starch degrading enzymes. Aliquots were mixed with toluidine reagent and read on a spectrophotometer at 635nm. Each run included five standards. Two samples from each vial were prepared for extraction and analyzed separately for comparison purposes. If the standards were not linear (R^2=0.99) the entire set of samples was rerun.

The data were analyzed as a standard two-way analysis of variance design for the overall combined data. Plots and months were both fixed effects. The analysis of variance, covariance, and correlation programs used were developed at the University of California's Biomedical Department (Dickson 1975). The March data was not included in the analysis.

RESULTS AND DISCUSSION

The initial height measurements of the seedlings were taken in August 1981. The results of a one-way analysis of variance (Table 1) were statistically significant. The production seedlings were the tallest at the start of the experiment.

Descriptive statistics for the variables measured in this study are shown in Table 2. The means for each variable are the average of all observations taken between September and December, except the leaf data which does not Include December. The leaves had been shed by the December harvest date. Height and caliper growth ceased by the October measurement date.

The two-way analysis of variance results (Table 3) show there was a significant nursery plot by month interaction for total root percent starch between September and December 1981. Figure- 2 illustrates the magnitude of the variation among plots for total root percent starch over the four month sampling period. Starch content rose from a mean of 18% to 28% for all plots from September to October. The mean starch percent levels for November and December were 30% and 29%, respectively. From October to December starch content tended to

Table 1 .-Results of the one-way analysis of variance and Duncan's Multiple Range Test for August height means of all of the seedlings per plot at the start of the experiment.

ANALYSIS OF VARIANCE TABLE

Source of Variation	df	ms	F value
Aug. Ht.	5	1029.71	42.17**1/
error	173	24.42	

DUNCAN'S MULTIPLE RANGE TEST2/

Plot	4	2	3	5	1	P3/
Aug. Ht. (cm) $\bar{x}$	25.3	26.0	28.9	30.4	31.5	41.2

1/ ** = significant at 99% confidence level.
2/ Means with a line in common are not significantly different at 95% confidence level
3/ P = Production.

remain fairly stable for a given plot with the exception of plot 1. Root percent starch rose steadily in plot 1. This suggests that October was the critical period in which starch content either reached or closely approached the peak level in a given plot - except plot 1. The drop in starch content between December and March indicated that the seedlings were entering another physiological state.

The relationship between changes in leaf dry weight and root starch by plot revealed some interesting observations. Between September and October starch content rose dramatically whether leaf dry weight increased or &creased (Table 4). Between October and November leaf dry weight decreased in every case, but the change in percent root starch was not as great as before, The trend in foliar nitrogen was decidedly downward for all three months. The trend for starch content was the opposite; thus, the negative correlation of -0.61 (Table 5) between leaf nitrogen and root starch.

The foliar potassium and magnesium levels in the production seedlings were significantly less than the foliar levels from the other five plots (Table 6). The difference is attributed to the lack of supplemental fertilization in the production area.

The two most common measures of growth nurseryman use are height and caliper. Both were significantly different for plots and months (Table 3). The simple correlations in Table 7 between total root percent starch and height or caliper were 0.06 and 0.21, respectively. Con-

Table 2 .--Mean, standard deviation, coefficient of variation, and range in values of the thirteen variables measured between September and December.

	Mean	Standard Deviation	Coeff. of Var.	Range
Height	42 cm	10.36	0.24	19.0 - 71.0
Caliper	6 mm	1.71	0.26	2.0 - 11.0
Leaf Dry Wt. 1/	1.79 g	1.07	0.60	0.2 - 6.1
Stem Dry Wt.	2.92 g	1.96	0.67	0.3 - 11.1
Tap Root Dry Wt.	2.33 g	1.64	0.70	0.11 - 10.36
Lateral Root Dry Wt.	0.89 g	0.92	1.03	0.09 - 7.30
Total Root Dry Wt.	3.37 g	2.84	0.84	0.14 - 19.43
Total Root % Starch 2/	25.94%	7.75	0.30	8.0 - 44.0
Leaf Nutrients11 (Percent)				
Nitrogen	1.75231	0.45	0.26	0.73 - 2.85
Phosphorus	0.16%	0.05	0.29	0.08 - 0.45
Potassium	0.89	0.24	0.27	0.33 - 1.49
Calcium	0.68	0.16	0.24	0.29 - 1.00
Magnesium	0.27	0.05	0.18	0.13 - 0.39

1/ Mean of values from September to November. No leaves were present in December.
2/ Percent of total root dry weight.
3/ Percent of total leaf dry weight.

Table 3.--The F Values from the Two-Way Analysis of Variance Results of Plots and Months between September and December

	Plot	Month	Plot x Month
Height	6.73**1/	3.22*	NS
Caliper	5.04**	6.49**	NS
Leaf Dry Weight2/	4.57**	1.94NS	NS
Stem Dry Weight	8.89**	8.45""	NS
Tap Root Dry Weight	6.41**	21.84**	NS
Lateral Root Dry Wt.	5.82**	15.42**	NS
Total Root Dry Weight	6.00**	18.43**	NS
Total Root % Starch	98.94	29.77	3.80**3/
Leaf Nutrients21			
Nitrogen	72.97	58.15	2.48*
Phosphorus	7.27	7.08	2.24*
Potassium	19.92**	9.67**	NS
Calcium	31.50	64.46	3.08**
Magnesium	12.90**	2.54	NS

1/ * = significant at 95% confidence level.
** = significant at 99% confidence level.
NS = Non-Significant.

2/ Includes only the months of September, October, and November. No leaves on seedlings by late December.

3/ For tests with significant interactions, the main treatment levels were ignored due to confounding between treatments. The F values presented here are for the reader's information.

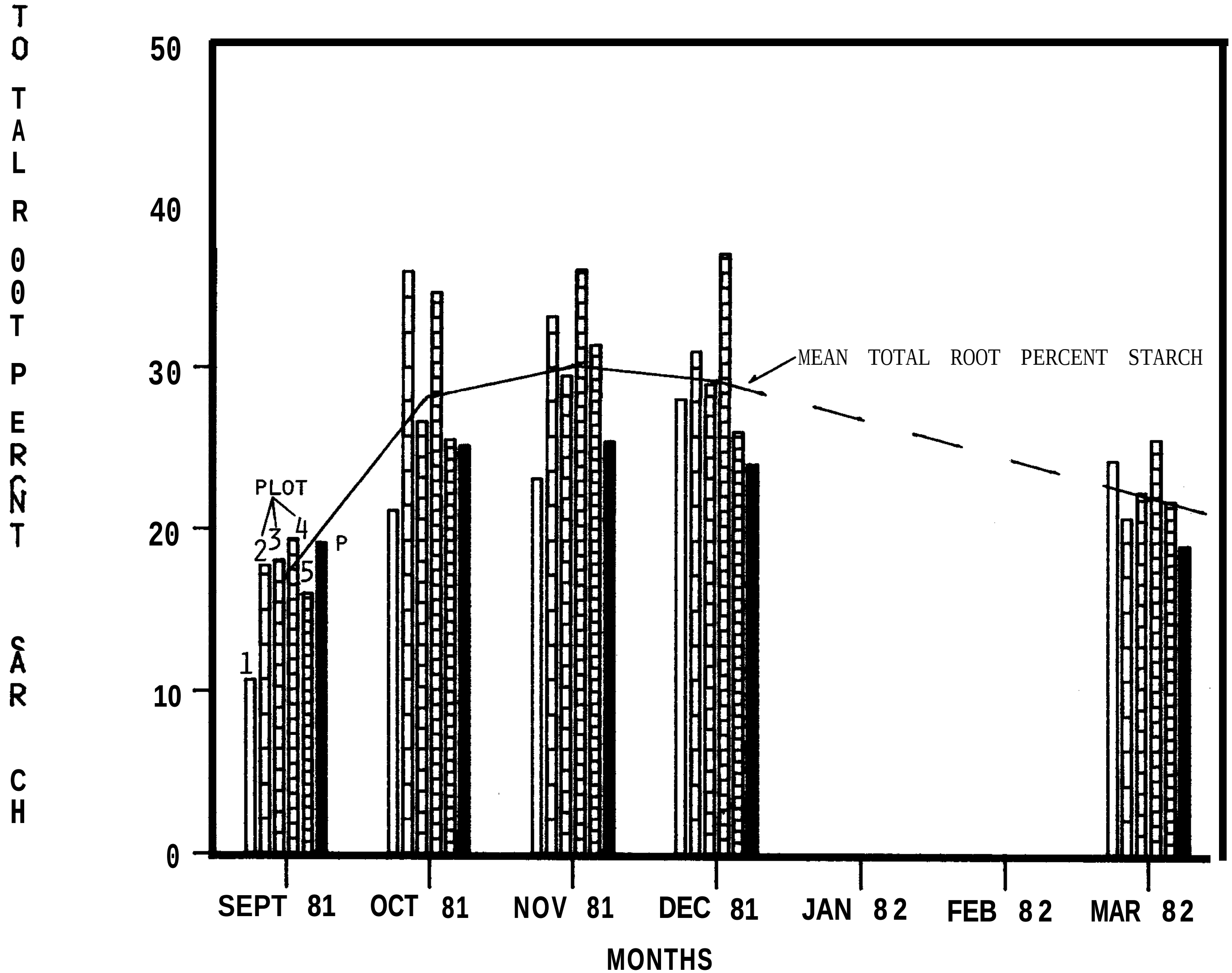

FIGURE 2. CHANGES IN TOTAL ROOT PERCENT STARCH FROM SEPTEMBER TO DECEMBER 1981,

Table 4 .--Absolute changes in leaf dry weight (g), total root percent starch, and leaf nitrogen content (% dry wt.) from September through November 1981.

Plot	September			October			November		
	Leaf (g)	Starch (%)	N (%)	Leaf (g)	Starch (%)	N (%)	Leaf (g)	Starch (%)	N (%)
1	1.54	10.9	2.57	3.02	21.0	2.24	2.34	23.1	1.73
	1.82	17.8	1.68	1.44	35.9	1.30	1.32	33.1	0.94
3	1.51	18.0	1.85	1.54	26.6	1.63	1.39	29.5	1.39
4	1.72	19.4	1.66	1.80	34.6	1.69	0.99	36.0	1.35
5	1.64	16.1	1.97	1.67	25.5	1.66	1.24	31.4	1.34
P*	3.02	19.3	2.24	2.11	25.1	2.29	2.01	25.4	1.94

Percent changes in leaf dry weight, total root percent starch, and leaf percent nitrogen.

Plot	September -> October			October -> November		
	Leaf	Starch	N	Leaf	Starch	N
1	+96%	+93%	-13%	-23%	+10%	-23%
2	-21	+102	-23	-8	-8	-28
3	+2	i-42	-12	-10	+11	-15
4	+5	+78	+2	-45	+4	-20
5	+2	+58	-16	-26	+23	-19
P*	-30	+31	+2	-5	+9	-15
	(Percent change from September level)			(Percent change from October level)		

* Production seedlings

Table 5.--Matrix of simple correlations (r) relating sweetgum seedling leaf nutrient levels with each other, total root percent starch, height (ht.), caliper (Cal.), and dry weight of the leaves, stems, and roots for the months of September, October, and November 1981.

Leaf Nutrients (Percent)*	N	P	K	Ca	Mg	Total Root % Starch	Ht.	Cal.	Leaf Dry Wt.	Stem Dry Wt.	Tap Root Dry Wt.	Lateral Root Dry Wt.	Total Root Dry Wt.
Nitrogen (N)	1.00	-0.09	-0.29	-0.68	-0.26	-0.61	0.20	-0.05	0.31	0.13	-0.15	-0.11	-0.17
Phosphorus (P)		1.00	0.38	0.24	0.28	-0.01	-0.23	-0.27	-0.16	-0.32	-0.32	-0.24	-0.28
Potassium (K)			1.00	0.55	0.28	0.19	-0.17	-0.31	-0.34	-0.33	-0.27	-0.28	-0.21
Calcium (Ca)				1.00	0.56	-0.49	-0.11	-0.03	-0.24	-0.21	-0.02	-0.07	-0.05
Magnesium (Mg)					1.00	-0.01	-0.33	-0.25	-0.30	-0.40	-0.33	-0.31	-0.35

* Percent based on leaf dry weight.

Table 6.--Results of the Duncan's Multiple Range Tests for months and plots. (Each number is the mean of 32 observations. Significance was determined at the 95% confidence level. Numbers with the same line in common are not significantly different.)

Caliper (mm)

Mon		Plot	
Sep	5.6	5	5.9
Oct	6.6	4	6.1
Nov	6.9	2	6.3
Dec	6.9	3	6.4
		1	6.5
		P[1]	7.7

Height (cm)

Mon		Plot	
Sep	38.6	3	35.4
Oct	42.3	2	37.8
Nov	43.6	4	41.6
Dec	44.5	5	43.6
		P	44.2
		1	49.4

Stem Dry Wt. (g)

Mon		Plot	
Sep	1.80	2	2.20
Oct	3.13	4	2.21
Nov	3.27	3	2.37
Dec	3.48	5	2.51
		1	3.53
		P	4.47

Total Root Dry Wt. (g)

Mon		Plot	
Sep	1.32	4	2.49
Oct	3.01	5	2.80
Nov	4.45	1	3.02
Dec	4.64	3	3.06
		2	3.22
		P	5.35

Lateral Root Dry Weight (g)

Mon		Plot	
Sep	0.32	4	0.57
Oct	0.74	5	0.66
Nov	1.10	2	0.71
Dec	1.46	1	0.88
		3	0.99
		P	1.50

Tap Root Dry Wt (g)

Mon		Plot	
Sep	1.01	3	1.10
Oct	2.27	4	1.78
Nov	2.83	1	2.13
Dec	3.21	5	2.14
		2	2.17
		P	3.51

Leaf Dry Wt[2] (g)

Plot	
3	1.48
4	1.51
5	1.52
2	1.53
1	2.30
P	2.38

Leaf % K

Mon		Plot	
Sep	0.80	P	0.57
Oct	0.96	3	0.92
Nov	0.90	2	0.93
		5	0.95
		1	0.96
		4	1.00

Leaf % Mg

Plot	
P	0.23
1	0.25
2	0.26
3	0.29
4	0.29
5	0.31

1/ P = Production Seedlings
2/ No leaves in December

Table 7.-Matrix of simple correlations (r) relating sweetgum seedling variables with each other for the months of September, October, November, and December 1981.

	Total Root % Starch	Ht.	Cal.	Stem	TAP	LAT	TRDW
Tot. Root % Starch	1.00	.06	.21	.15	.35	.15	.31
Height (Ht)		1.00	.59	.77	.56	.39	.47
Caliper (Cal)			1.00	.81	.83	.73	.75
Stem Dry Wt.				1.00	.84	.74	.77
Tap Root Dry Wt. (TAP)					1.00	.83	.92
Lateral Root Dry Wt. (LAT)						1.00	.82
Total Root Dry Wt.(TRDW)							1.00

Table 8.--Percent increases in plot height between initial plot height means and the means of the harvest height measurements of the same 32 seedlings sampled between September and December.

Plot	Initial Ht. Means (Aug)	Harvest Ht. Means (Sept to Dec)	% Change between initial Ht. & Harvest Ht
1	31.5 cm	49.4 cm	+57% (17.9 cm)
2	26.0	37.8	+45% (11.8 cm)
3	28.9	35.4	+22% (6.5 cm)
4	25.3	41.6	+64% (16.3 cm)
5	30.4	43.6	+43% (13.2 cm)
P*	41.2	44.2	+7% (3.0 cm)

* P = Production Seedlings

slder, that in a predictive sense only 0.4 and 4 percent of the variation in total percent root starch could be explained by caliper or average total height alone, respectively.

The low correlation between height growth and starch content can be seen by subtracting the Initial plot height means in August from the mean of the harvest height measurements of the same 32 seedlings sampled between September and December. The percent increase in height gives an indication of how much the seedlings in each plot grew (Table 8). The production seedlings changed the least in height. The percent changes In mean height for plots 1 and 4 were the largest.

The fact that root starch content is not strongly correlated with any of the other factors such as height, caliper, or dry weight brings Into question the possible use of starch as one measure of dormancy. However, the rather consistent and individual way in which the seedlings in each plot appeared to store starch would indicate that the plot locations were under different environmental conditions such as might be caused by a soil moisture gradient between seedling beds. High soil moisture is a soil management problem in this part of the nursery.

Based on observation of decreasing leaf dry weight over time per plot, the seedlings approached the seasonal dormancy period split roughly into two groups on the basis of leaf fall. Plot 1 and the production seedlings retained their leaves longer and had the lowest root percent starch contents between September and November. Those seedlings that retained their leaves tended to store less starch. This result certainly fits the concept of starch accumulation in hardwoods as outlined by Levitt (1972) - carbohydrate accumulation that takes place long before the hardening period, mostly in the form of starch, with a starch to sugar conversion after hardening off.

These results certainly support the idea that seedlings of similar appearance as measured by height and caliper are not the same internally. The production seedlings barely grew at all in height during the September to December period and maintained a relatively low constant total root percent starch (Figure 2). The seedlings in plot 1 continued to grow, retained their leaves longer (Table 8), and failed to accumulate a high amount of starch early In the fall. A sharp rise in starch content late in the growing season (October) may indicate that the dormancy mechanisms have been set in motion. However, the magnitude of the change may not be as important as the beginning starch level in early fall and the month in which the starch content peaks. The starch to sugar conversion is also important since It represents a shift in physiological condition. Knowing the level of the starch peak and when It occurs may give some indication of how well the seedling will tolerate cold storage and grow after outplanting. Unfortunately, no judgement can be made at this point as to what such diverse physiological differences among dormant seedlings may mean.

CONCLUSIONS

Sweetgum seedlings are capable of storing widely differing amounts 'of starch at any time during the fall or early winter under what could be considered similar growing conditions. In general, the greatest single increases in root starch content in each plot occurred between September and October. After that early increase the month to month shifts in starch content were less dramatic. These data suggest how critical that short time period in the fall may be to producing seedlings of a desired physiological quality in coastal South Carolina.

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THE EFFECT OF PHOTOPERIOD DURING COLD STORAGE ON THE SURVIVAL AND GROWTH OF LOBLOLLY PINE SEEDLINGS[1]

Jon D Johnson[2]

Abstract.--Operational cold storage of pine seedlings is widely used throughout the South. The cold storage environment is extremely artificial and is known to reduce the survival and growth of seedlings when compared to the survival and growth of freshly lifted seedlings. The objective of this study was to assess the effect of photoperiod during cold storage of loblolly pine seedlings. Seedlings packaged in either Virginia Division of Forestry seedling bales or modified Kraft-polyethylene bags were exposed to a photoperiod of 0 hour, 8 hour or 16 hours during cold storage at 2°C. After two months of storage, the bulk of the seedlings were outplanted on a converted pine-hardwood site in the Piedmont of southern Virginia. Excess seedlings from each treatment were potted and grown in a greenhouse for intensive measurements. The seedlings were sampled for survival and bud activity during the first two months after planting, and for survival and total height after the growing season. Survival in the field and greenhouse studies appeared to be controlled by seedling hydration during storage. The photoperiod treatments accelerated bud activity with the longer photoperiods causing faster bud break. This accelerated bud activity was manifested in taller seedlings at the end of the growing season. The data suggest that the seedling response was not due to additional photosynthesis during storage, but due to a photoperiodic effect on changes in endogenous growth regulators.

INTRODUCTION

The planting of southern pines customarily began in late November and progressed to the first of March. Early research indicated that seedlings lifted and planted during this period had the highest survival (Dierauf, 1973; Wakeley, 1954). As the area of annually reforested lands in the South increased, the planting season had to be extended. This extension was accomplished by the introduction of low temperature storage for the lifted seedlings (Miller, 1980; Willston, 1974). Nearly all of the southern pines planted today pass through cold storage, at least temporarily.

Vigor of stored seedlings varies with date of lifting, i.e. degree of dormancy, storage temperature and duration in storage. Dormancy, depending on the definition used, may or may not truly occur in southern pines (Perry, 1971a). Regardless of this problem, research substantiates that seedlings lifted too early in the fall or too late in the winter exhibit poor storage life and low survival when planted immediately. Ideal storage temperature for southern pines is slightly above freezing at 2°C (Williston, 1974). Temperature deviation of several degrees in either direction will decrease storage life and survival (Miller, 1980). The duration of cold storage should be minimized. The best survival and performance usually occur in seedlings which are immediately planted after lifting (Dierauf and Marler, 1979). Dierauf (1973) reported that loblolly seedlings could be stored for up to three and a half months

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without a reduction in survival providing that the seedlings were dormant when placed into storage. Some northern species remain in storage for six months prior to planting (Miller, 1980).

Cold storage as practiced today represents an artificial environment in comparison to the natural, field environment. Light is totally excluded and temperature is fairly constant around both the shoot and roots. Under field conditions, seedlings are exposed to light and there is usually a temperature difference between the roots and shoots. Most importantly, the roots are warmer than the shoots and the shoots are exposed to sunlight.

Measurement of dry weight accumulation and photosynthesis during the winter months suggests that these months are important to the physiological well-being of seedlings. Bradbury and Malcolm (1978) found that dry weight of Sitka spruce (Picea sitchensis) seedlings doubled between late September and mid-April in southern Scotland. They further reported that the dry weight increase was similar in the roots and shoots until mid-January after which proportionally more dry weight accumulated in the needles. Perry (1971b) observed similar dry weight increases in loblolly pine (Pinus taeda) and sweetgum (Liquidambar styraciflua). Between December 20 and April 1, sweetgum increased dry weight by 42 percent and loblolly pine increased by 62 percent even though night temperatures were frequently below -5°C. It is known that trees will photosynthesize during the winter which is probably responsible for the observed dry weight increases. Strain et al. (1976) observed photosynthetic rates in loblolly pine seedlings of between 8 and 11 mg CO_2 g^{-1} h^{-1} at 5°C under controlled environment. Correlative field measurements in this same study indicated net photosynthetic rates of 1.5 mg CO_2 dm^{-2} h^{-1} at 600 μE m^{-2} s^{-1} and 3.0 mg CO_2 dm^{-2} h^{-1} at 2200 μE m^{-2} s^{-1} while the air temperature ranged from 5° to -10°C. The artificial environment of cold storage may have an adverse effect on seedling physiology during storage and this may carry over after outplanting.

Stored seedlings exhibit dry weight losses proportional to duration in storage. Wilner and Vaartaja (1958) observed weight losses of four deciduous species to range from 3.3 percent to 7.2 percent during cellar storage. In a review by Aldhous (1964), weight loss during cold storage was reported to be between one and two percent and very seldomly three percent after several months' storage. He concluded that survival was best when weight loss was minimized. In more recent research, Buckley and Lovell (1974) reported a 41 percent decrease in dry weight of Sitka spruce seedlings stored for 20 weeks. Analyzing weight changes in roots and shoots, they found that root dry weight decreased only 17 percent in 20 weeks of storage whereas shoot dry weight decreased 48 percent. They concluded that main and lateral shoot needles were most adversely affected by storage. Red pine and white spruce showed about a 4 percent dry weight decrease during 100 days of cold storage (van den Driessche, 1979). Furthermore, dry weight reduction rate was found to be related to respiration rate during storage. Three-year-old Scots pine lost only 3 percent dry weight after six months of storage when sealed in plastic bags, but seedlings in unsealed containers had higher rates of loss (Langstrom, 1971 cited in van den Driessche, 1979).

The effect of photoperiod on seedlings during cold storage has received very little attention in the literature. Deffenbacher and Wright (1954) noted that there was evidence that light retards molds which grow on seedlings stored in the dark. Lavender and Wareing (1972) concluded that the deleterious effects of dark storage, i.e. poor root regeneration, could be greatly reduced by a daily exposure to several hours of low light intensity illumination. Additionally, they felt that this light effect was not attributable to photosynthesis, but to a more favorable hormone balance, specifically gibberellins. A continuation of this research was reported by Lavender (1978). Bud activity of Douglas-fir seedlings was monitored after cold storage under 0, 8 and 16 hour photoperiod. Plants maintained at low temperatures were found to resume active growth more rapidly when exposed to a long daily photoperiod. Unfortunately, he did not sample dry weights or any other physiological parameter which could have provided an understanding of the response.

The purpose of this study was to assess the effect of photoperiod during cold storage of loblolly pine on seedling survival and growth.

METHODS AND MATERIALS

Seedlings of Pinus taeda were machine lifted in mid-December, 1981 from the Virginia Division of Forestry (VDF), New Kent Forestry Center Nursery, packaged, and placed into 2°C cold storage. On January 4, 1982, three light treatments were imposed during cold storage: 1) Control, no light; 2) 8 hour photoperiod under four-40 Watt Gro-lux fluorescent lamps, photosynthetic photon flux density of 150 μE m^{-2} s^{-1}; and 3) 16 hour photoperiod under same light as in 2). Two VDF seedling bales (1000 seedlings per bale) per treatment were used to account for variation among bales (Tom Dierauf, personal communication). Additionally, at the time the photoperiod treatments were imposed, 800 seedlings per light treatment were packaged in a modified Kraft-polyethylene bag to test packaging effects; the bags were cut in half and the bags were placed upright to expose the shoots. Storage lasted for two months.

The seedlings were sampled before and after storage for root, stem and needle biomass (dry weight), and root collar diameter. Height was not measured initially because all seedlings were fairly uniform in size due to top clipping practices in the nursery.

After storage, the bulk of the seedlings were outplanted at the Reynolds Homestead Research Center, Critz, Virginia. The study employed a randomized split-block design. Four blocks of 1/4 acre each were planted at a 4' x 4' spacing. One hundred seedlings per treatment of six treatments were planted on each block. To account for variability among VDF bales, seedlings from different bales were planted separately.

Mortality and bud activity (see description below) were measured monthly for the first two months in the field. First year mortality was measured in late September.

To further quantify differences in growth among treatments, 10 seedlings per treatment and 10 seedlings lifted from the seedbed when the other seedlings came out of storage (fresh lifted) were potted and grown in a greenhouse. Intensive measurements were made of the bud activity during the first two months after planting. The bud activity of the seedlings was assessed weekly after planting using the following numerical rating system: 0 = no bud activity; 1 = bud swelling; 2 = stem elongation beginning; and 3 = continued stem elongation and elongation of needle primordia. After the seedlings had set a winter bud (October 1), they were measured for dry weight, root collar diameter and total height.

RESULTS

Cold Storage

The dry weight changes in the roots, stems and needles during cold storage are presented in Figure 1. There were no consistent trends in the dry weight changes with photoperiod treatment. However, the dry weights of seedlings in the VDF bales in the 8 and 16 hour photoperiod exhibited increases during storage. The fresh-lifted seedlings showed dry weight increases in root and stem tissue, and a decrease in the needles. Total dry weight increase of the fresh-lifted seedlings was four percent.

During planting of both studies, two seedling packages were observed to have dried during storage. One VDF bale in the 8 hour photoperiod treatment and the 16 hour bag treatment had dried to the point where the kaolin clay-dip on the roots had become powdery. This low water content during storage was manifested in lower survival and bud activity.

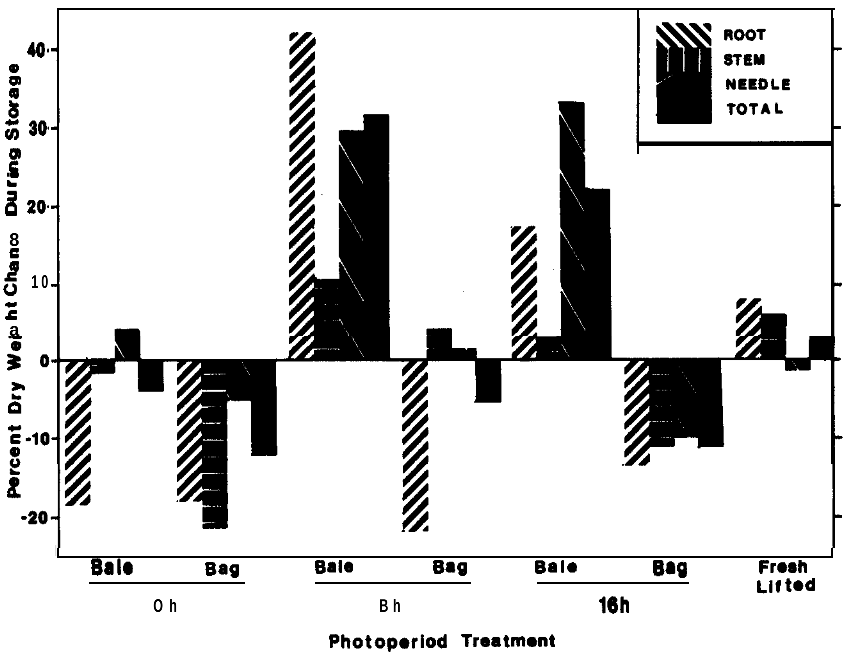

Figure 1. The percent dry weight changes in the root, stem, needle and total of loblolly pine seedlings stored for two months at 2°C. The seedlings were treated to different photoperiods and packaging in cold storage.

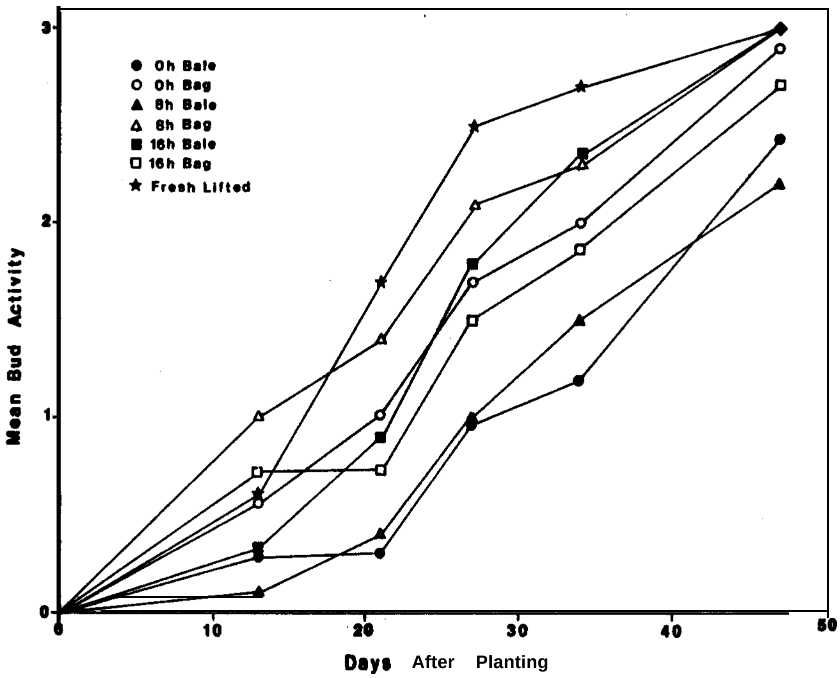

Figure 2. The mean bud activity of loblolly pine seedlings grown in a greenhouse. The bud activity stages are: O-no activity; l-bud swelling; P-stem elongation; 3-continued stem elongation and elongation of needles.

Greenhouse Study

Seedling survival in this study was high, as expected. Pour of the seven treatments exhibited 100 percent survival. Bale 0 hour and 8 hour had 90 percent survival, and bag 16 hour had 70 percent survival. This mortality is reflective of the observation made above; however, the bale 0 hour seedlings appeared adequately hydrated when they came out of storage.

Bud activity was strongly influenced by the photoperiod treatments (fig. 2). Two weeks after planting, the 8 hour and 16 hour bag treatment seedlings showed the most activity. A week later the 16 hour bag seedlings stagnated and lagged behind most of the other treatments. Although the fresh lifted seedlings lagged initially, they

Table 1 .--The number of days to reach a mean bud activity of 1 and 2 in loblolly pine seedlings growing in a greenhouse. The seedlings were treated to different photoperiods and packaging during two months of cold storage at 2°C.

		Mean Bud Activity	
Package	Photoperiod	1.0	2.0
	(h)	Time (days)	
Bale	0	27	43
	8	27	42
	16	22	29
Bag	0	21	34
	8	13	26
	16	24	36
Fresh Lifted		16	23

ultimately exhibited the highest bud activity. The slowest seedlings to break bud were in the 0 hour and 8 hour bale treatments. The.other treatments were intermediate in their response.

From figure 2, the number of days to achieve a mean bud activity of 1.0 and 2.0 was determined (Table 1). Whereas it took seedlings from the 8 hour bag treatment only 13 days to reach a mean bud activity of 1.0, i.e. bud swelling , both the 0 hour and 8 hour bale treatment seedlings required twice as long, 27 days, to reach the same activity. Fresh-lifted seedlings began stem elongation (bud activity of 2.0) only 23 days after planting and it took the 8 hour bag treatment seedlings an additional three days, 26 days total, to achieve the same activity. The 0 hour bale seedlings were the slowest to break bud, requiring 43 days to achieve a mean bud activity of 2.0.

The mean bud activity correlated well with mean seedling height measured six months later (fig. 3). The mean bud activity measured on April 16 and April 23 gave coefficients of determination of 0.99 and 0.88, respectively when regressed with total height. The 8 hour bale treatment, however, was an outlier and was not included in the regression. The validity of these regression equations is supported by the nearly equal intercept values, 22.12 and 22.32. The intercept values represent the mean seedling height in centimeters at the time of planting.

Field Study

Field survival of the seedlings by treatment again showed the influence of water content during storage (fig. 4). Both 8 hour bale and 16 hour bag seedlings had low survival, 67 and 64 percent respectively, after the first year in the field. All of the other treatments had comparable survival, on the order of 85 percent.

Seedling bud activity in the field was much lower than in the greenhouse study (Table 2). One month after planting, seedlings in all of the treatments had a mean bud activity of only 0.45. This indicates that roughly half of the seedlings had swollen buds. Treatment effects became evident two months after planting. As in the greenhouse study, the 8 hour bag treatment seedlings had the highest activity with a mean of 2.28. Both 0 hour and 8 hour bale treatment seedlings were low, similar to the greenhouse study. However, the 16 hour treatment seedlings had the lowest bud activity in the field with a mean of 1.72. The 16 hour bale and 0 hour bag treatment seedlings were similar in bud activity, paralleling the greenhouse study results.

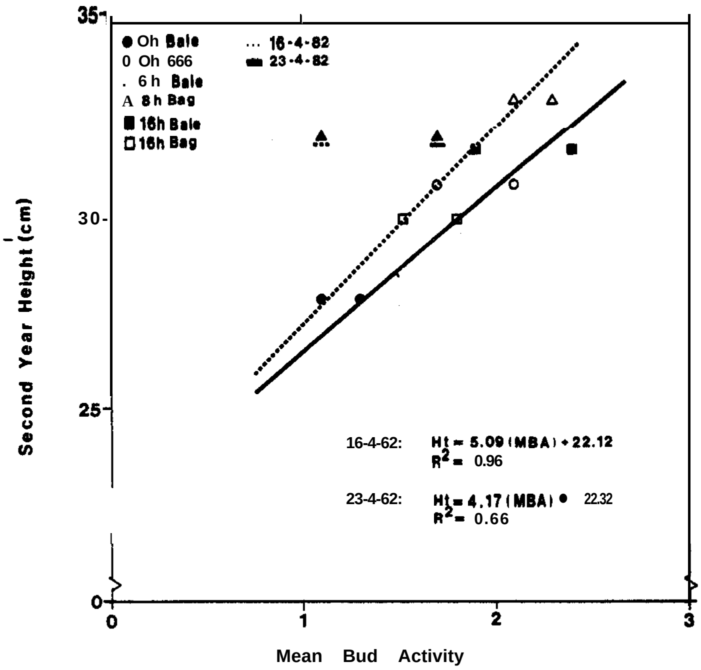

Figure 3. Second year height after growing for six months in a greenhouse as it relates to the mean bud activity measured at two times in the spring.

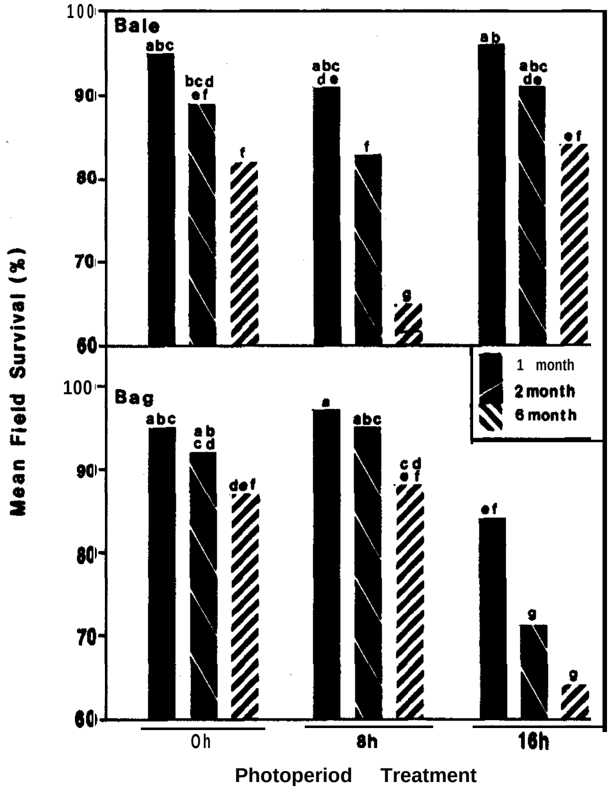

Figure 4. The mean field survival of loblolly pine seedlings after 1, 2, and 6 months by photoperiod and packaging treatment. Each mean is based on a sample of 400 seedlings. Means with the same letter are not significantly different at 95% probability level.

Table 2 .--The mean bud activity of loblolly pine seedlings after one and two months in the field as affected by photoperiod and packaging during two months cold storage at 2°C. Values reported are the means ± standard error of 400 seedlings. The bud activity stages are: 0 - no activity; 1 - bud swelling; 2 - stem elongation; 3 - continued stem elongation and elongation of needles.

Package	Photoperiod	Time After Planting	
		1 month	2 month
	(h)		
Bale	0	0.48 f0.02	1.82 ±0.07
	8	0.41 ±0.04	1.86 ±0.13
	i6	0.43 ±0.04	2.02 ±0.09
Bag	0	0.45 ±0.04	2.03 ±0.11
	8	0.46 ±0.06	2.28 ±0.10
	16	0.43 ±0.05	1.72 r0.12

DISCUSSION

The dry weight losses during cold storage (Table 1) were similar to those reported for red pine and white spruce (van den Driessche, 1979), Scots pine (Langstrom, 1971 cited in van den Driessche, 1979) and other forest tree seedlings (Aldhous, 1964). Buckley and Lovell (1974) reported losses of 17 percent in root dry weight and 48 percent in shoot dry weight of Sitka spruce stored for 20 weeks. In the present study with only 8 weeks of storage, root dry weight losses were consistently greater than losses in shoot dry weight.

The dry weight increase recorded for all of the tissue of the 8 hour and 16 hour bale treatment seedlings conflicts with all previous reports. The possibility exists that larger than average seedlings were sampled out of these treatments, thus biasing the mean dry weight.

The fresh-lifted seedlings exhibited only a slight increase in dry weight during two months in the seedbed. This conflicts with the paper of Bradbury and Malcolm (1978) which reported a doubling in dry weight in Sitka spruce during the winter. Likewise, Perry (1971b) reported a 62 percent increase in the dry weight of loblolly pine seedlings between December and April. It is very probable that significant dry weight increases occur primarily in early winter (December) and late Spring (March) when the environmental conditions are more suitable for photosynthesis.

Photosynthesis as a contributing factor for the observed treatment response can be safely eliminated. First, the photosynthetic photon flux density of the lights in the photoperiod treatments was less than 10 percent of full sunlight. There is a good possibility that the light compensation point for photosynthesis was not surpassed. Secondly, there were no consistent dry weight increases in the seedlings exposed to the two photoperiods which would have suggested that net photosynthesis was occurring.

With other factors being equal, it was hypothesized that the response in bud activity to photoperiod should have been: 16 hour > 8 hour > 0 hour. Likewise, it was hypothesized that the bud activity response to package treatment should have been: bag > bale, due primarily to the self-shading effect of the bale lying in the horizontal position. As indicated in figure 2 and Table 1, the order of bud activity was fresh-lifted (as expected from previous work; Dierauf and Marler, 1969) > 8 hour bag > 16 hour bale > 0 hour bag > 16 hour bag > 8 hour bale > 0 hour bale. Both the 16 hour bag and 8 hour bale were lower than expected, but this can be attributed to their excessive drying during storage. In all cases, however, bud activity was accelerated over the control, 0 hour *bale,* even when seedlings had dried out during storage. The large disparity between 0 hour bag and 0 hour bale seedlings may be attributed to the orientation of the seedling axes during cold storage. In the bale treatments, the seedlings were stored in a horizontal fashion, whereas the seedlings in the K-P bags were in a vertical orientation. It is well-known that orientation influences the distribution and transport of plant growth regulators (Zimmerman and Brown, 1975). For this same reason, bud activity in the field was equal for 0 hour bag and 16 hour bale (Table 2). Seedling bud activity in the field was 8 hour bag > 0 hour bag = 16 hour bale > 8 hour bale > 0 hour bale > 16 hour bag.

The results of the bud activity in the present study are supported by the work reported by Lavender (1978) with Douglas-fir. He found that the longer the photoperiod during storage, the more accelerated was bud activity. As discussed above, the accelerated bud activity was not attributed to a photosynthetic response. Lavender and Wareing (1972) concluded that the accelerated bud activity due to a photoperiod treatment was a result of changes in gibberellin (a plant growth stimulator) concentration in the buds of Douglas-fir rather than being due to photosynthesis. More recently, abscisic acid (a plant growth inhibitor) concentration in buds has been found to change seasonally in a number of species (Harrison and Saunders, 1975; Webber, et al. 1979). Growth inhibitor concentration consistently decreased prior to bud break. Additionally, abscisic acid has been demonstrated to be photosensitive, photoisomerizing to a biologically inactive isomer and even photo-oxidizing into inactive metabolites (Johnson, 1981). It may be, therefore, that the photoperiod treatments accelerate the concentration decrease of abscisic acid in the buds, allowing them to become metabolically active sooner after planting.

The use of photoperiod treatments during cold storage to accelerate bud activity can be justified only if the treatment response continues through the growing season. Under greenhouse conditions, the correlation between bud activity in the spring and final height was quite good (fig. 3). The true test, however, will come with the analysis of the field study data.

Data have been presented showing that the presence of low intensity light during cold storage of pine seedlings accelerates bud activity after planting. This accelerated bud activity is carried over the growing season resulting in taller seedlings at the end of the season. The maintenance of a favorable water status during storage is parsmount to minimizing seedling mortality.

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THE DEVELOPMENT OF ECTOMTCORRHIZAE ON CONTAINERIZED

SWEET BIRCH AND EUROPEAN ALDER SEEDLINGS FOR

PLANTING ON LOW-QUALITY SITES[1/]

R. F. Walker, D. C. West, and S. B. McLaughlin[2/]

Abstract.--A study was initiated to assess the potential of Pisolithus tinctorius as an ectomycorrhizal associate of containerized sweet birch (Betula lenta) and European alder (Alnus glutinosa) seedlings and to determine the effect of this fungal symbiont on seedling growth. In a test of sweet birch and European alder grown in Leach tubes, P. tinctorius formed abundant ectomycorrhizae on sweet birch when introduced via a vegetative mycelial inoculum. Cenococcum geophilum, originating from sclerotia present in the potting medium, and Thelephora terrestris, introduced via wind-borne propagules, formed ectomycorrhizae on the sweet birch seedlings inoculated with P. tinctorius and on the sweet birch control seedlings. C. geophilum also formed ectomycorrhizae on the inoculated and control European alder seedlings, but an inoculation with P. tinctorius did not result in the formation of P. tinctorius ectomycorrhizae on this host. Sweet birch seedlings infected with P. tinctorius had a greater dry weight, height, root collar diameter, and volume and a lower shoot/root ratio than the sweet birch control seedlings, and European alder seedlings with abundant C. geophilum ectomycorrhizae exhibited a similar improvement in growth in comparison with European alder with lesser C. geophilum infections. The inoculation of containerized sweet birch and European alder seedlings in the nursery with the appropriate ectomycorrhizal symbiont may facilitate the establishment of these species on harsh sites such as surface mine spoils.

INTRODUCTION

Formal and informal studies involving performance comparisons among tree species of potential value for the revegetation of surface-mined lands were carried out extensively in the earlier years of reclamation research (Ashby et al. 1980, Boyce and Merz 1959, Boyce and Neebe 1959, Brown 1962, Chapman 1944, Clark 1954, Czapowskyj 1970, Czapowskyj and McQuilkin 1966, DenUyl 1962, Finn 1958, Geyer 1971, Geyer 1973, Hart and Byrnes 1960, Horn and Ward 1969, Limstrom 1952, Limstrom 1960, Limstrom and Deitschman 1951, Medvick 1973, Miles et al. 1973, Plass 1975). Portions of the data generated in these studies have been used in the development of planting guides to facilitate species selection (Boyce and Neebe 1959, Limstrom 1960, Vogel 1981). Nevertheless, the revegetation of surface mine sites with forest tree species has often been

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discouraged in recent years due to social, political, legal, economic, or technical reasons (Smith 1980, Vogel 1979, White 1980). Many of the species with apparent potential for the revegetation of these sites have not been deployed due to deficiencies in establishment techniques which result in a poor overall performance. Two recent developments in the practice of forestry have potential for alleviating this problem: (1) the inoculation of seedlings in the nursery with a mycorrhixal fungus and (2) the use of containerized planting stock. Survival and growth on adverse sites may be greatly enhanced by the planting of selected species of containerized seedlings with well-developed mycorrhizal root systems.

There is ample evidence which suggests that some mycorrhizal fungi have a superior ability to provide benefits to their hosts under the adverse conditions prevalent on surface mine spoils. These sites are often characterized by a low pH, low nutrient status, high concentrations of toxic substances, elevated surface temperatures, and droughtiness. Many workers (Hile and Hennen 1969, Lampky and Peterson 1963, Marx 1975, Marx 1977, Medve et al. 1977, Schramm 1966) have reported the occurrence of basidiocarps of Pisolithus tinctorius (Pers.) Coker and Couch associated with several forest tree species on various mine spoils, and pine seedlings with an induced infection by P. tinctorius have been shown to exhibit survival and growth superior to that of noninoculated seedlings infected with naturally occurring fungal symbionts on many adverse sites (Berry and Marx 1978, Marx 1976, Marx 1980, Marx and Artman 1979, Walker et al. 1981). The general techniques developed for the inoculation of bare-root seedlings in the nursery with P. tinctorius (Marx 1969, Marx and Bryan 1975) have been shown to be applicable to containerized seedlings as well (Dixon et al. 1981, Goodwin 1980, Marx and Barnett 1974, Marx et al. 1982, Molina 1979, Ruehle 1980, Ruehle and Marx 1977, Ruehle et al. 1981).

Limited research has been conducted concerning the application of containerization to the reforestation of harsh sites (Davidson and Sowa 1974a, Davidson and Sowa 1974b, Goodman et al. 1977), but the results of these studies have been inconclusive. It is generally accepted that the biological advantages of planting containerized seedlings on routine sites, i.e., the planting of intact root systems with little or no loss of fine roots and the availability of a short-term external supply of nutrients and water in the rooting medium, would prove to be of even greater importance on adverse sites.

The study reported here was designed to examine the feasibility of infecting containerized sweet birch (Betula lenta L.) and European alder (Alnus glutinosa [L.] Gaertn.) seedlings with P. tinctorius for use in the revegetation of adverse sites. Sweet birch occurs naturally on a wide variety of less favorable sites with rocky, coarse-textured, or shallow soils (Brooks 1920, Frothingham 1915, Frothingham 1931, Harlow and Harrar 1969, Illick 1915, Leak 1958, Tryon 1943) and has been considered a species of potential value for purposes of soil protection and stabilization (Illick 1915). Tryon and Markus (1953) found sweet birch growing on iron ore spoil banks in West Virginia, and it has also been identified as a volunteer species on coal spoils in West Virginia (Brown and Tryon 1960) and Pennsylvania (Schramm 1966). Plass (1975) evaluated the reclamation potential of this commercially important species on a coal spoil in Kentucky and found it to exhibit excellent survival and growth after four years. Preliminary examinations of the mycorrhizal associations of sweet birch have indicated P. tinctorius to be one of its most prevalent fungal symbionts on harsh sites (Marx 1975. Schramm 1966) and this host species has proven to be extremely receptive to induced infections by P. tinctorius using a vegetative mycelial inoculum (Walker et al. 1982). European alder has long been advocated as a-reclamation species in Europe (Rohnke 1941) and has gained considerable recognition in the United States for this potential (Bennett et al. 1978, Dale 1963, Funk 1973, Funk and Dale 1961, Limstrom 1960, Lowry et al. 1962, Miles et al. 1973). This species offers substantial ameliorative qualities when planted on adverse sites due to its ability to fix atmospheric nitrogen via nonleguminous root nodulation (Stewart 1967). European alder is a known host of ectomycorrhizal fungi (Trappe 1962), and D. H. Marx[3/] (personal communication) has observed P. tinctorius basidiocarps associated with European alder on harsh sites in the Tennessee Copper Basin.

MATERIALS AND METHODS

The vegetative inoculum of Pisolithus tinctorius used in this study was produced by Abbott Laboratories by the method described by Marx et al. (1982).[4/] It consisted of fungal mycelia grown on a vermiculite-peat moss-nutrient medium substrate such that the hyphae permeated the vermiculite particles. A sterile mixture of vermiculite and 5% peat moss by volume replaced the P. tinctorius inoculum for the production of control seedlings.

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Sweet birch and European alder seeds from an east Tennessee source were stratified under moist conditions at 3°C for eight weeks. Germination tests revealed the germination success of the seed lots of both species to be approximately 25%. The water rinse sterilization method of R. P. Karrfalt[5/] (personal communication) was used to sterilize the seeds of both species.

A 1:1 volume ratio of peat moss and horticultural grade vermiculite steam sterilized at 128°C for 40 minutes was used as the potting medium. The P. tinctorius inoculum was incorporated into the potting medium at the volume ratio of 1:15 such that an even distribution of the inoculum was assured. Single-celled Leach tube containers, 165 ml capacity, were filled with the inoculated potting medium and sown with five sweet birch or European alder seeds. Control containers were prepared in an identical manner except that a sterile mixture of vermiculite and neat moss was used in the place of the P. tinctorius inoculum. One hundred fifty containers of each host species-ectomycorrhizal treatment combination were distributed in six replicate blocks of 25 containers each. The seeds were misted for 10 minutes twice daily until germination; all containers were then thinned to one seedling each.

The seedlings were grown under greenhouse conditions from September 1979 through March 1980. The temperature in the greenhouse ranged from a maximum of 32°C during the day to a minimum of 26°C at night. The photoperiod was maintained at 16 hours using Gro & Sho® fluorescent lamps. A soluble 20-20-20 NPK fertilizer dissolved in distilled water was applied to all seedlings at the rate of approximately 45 mg/seedling at each fertilization. The fertilizer was applied every three weeks from October through March. Sequestrene® 330 Fe iron chelate was applied with the second fertilization at the rate of approximately 3.0 mg/seedling. All seedlings were watered twice weekly. The position of the seedlings within each replicate block and the position of each replicate block was changed weekly to insure that all seedlings were subjected to similar overall growth conditions.

Three months after seeding, and again after six months at the completion of the study, measurements of height and root collar diameter were made on all seedlings and an estimate of seedling volume was determined by multiplying the height of each seedling by the square of its root collar diameter (Marx et al. 1977a). Two seedlings from each of the six replicate blocks of each host species-ectomycorrhizal treatment combination were randomly selected at the termination of the study to assess their ectomycorrhizal development. The roots of these seedlings were washed free of potting medium and the percent ectomycorrhizal formation by symbiont was determined by ascertaining the total number of short roots of each root system, determining the number of short roots infected by each specific fungal symbiont, and expressing the level of infection of each symbiont as a percentage. Each symbiont was identified by the characteristic appearance of its ectomycorrhizae. These seedlings were then oven-dried at 100°C for 24 hours, the shoot and root dry weights were measured, and the shoot/root ratio was determined. The differences between the treatment means of each host species were evaluated with the t test.

RESULTS

Pisolithus tinctorius formed abundant ectomycorrhizae on the roots of the sweet birch seedlings in response to the inoculum incorporated into the potting medium prior to *seeding* (Table 1). None of the sweet birch control seedlings examined were infected with P. tinctorius. Naturally occurring ectomycorrhizae resulting from an infection by Cenococcum geophilum Fr. and Thelephora terrestris (Ehrh.) Fr. were found to have formed to a minor extent on the inoculated sweet birch seedlings and comprised the total ectomycorrhizal development on the sweet birch control seedlings. The isolate of P. tinctorius used in this study did not form ectomycorrhizae on the roots of the European alder seedlings. C. geophilum ectomycorrhizae formed on both the European alder inoculated with P. tinctorius and on the control seedlings, but were considerably more abundant on the inoculated seedlings.

The growth of the sweet birch seedlings was significantly increased by the infection with P. tinctorius. The total dry weight was increased 41%, and the relatively greater root weight of the seedlings with P. tinctorius resulted in a 30% reduction in the shoot/root ratio, indicating that these seedlings had a superior balance commonly desired for successful establishment in the field (Table 2). Significant differences also occurred in the growth in height and root collar diameter (Table 3). The seedlings with P. tinctorius were 13% greater in height and 30% greater in root collar diameter than the control seedlings after three months, and 21% and 19% greater in height and root collar diameter, respectively, after six months. These growth differences became even more apparent when the estimate of seedling volume was calculated. Reflecting the increased growth in both height and *root* collar diameter, the volume of the seedlings with P. tinctorius was 83% greater after three months and 64% greater after six months than that of the control seedlings.

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Table 1.--The ectomycorrhisal development of containerized sweet birch and European alder seedlings inoculated with *Pisolithus tinctorius* and control seedlings after six months growth.

Treatment	Ectomycorrhizal Infection (%)[1/]				Seedlings with *Pisolithus tinctorius* (%)
	Pisolithus tinctorius	*Cenococcum geophilum*	*Thelephora terrestris*	Total	
Sweet Birch					
Inoculated	27	2	3	32	100
Control	0	5	4	9	0
Level of Significance[2/]	NA	**	NS	**	NA
European Alder					
Inoculated	0	22	0	22	0
Control	0	7	0	7	0
Level of Significance[2/]	NA	**	NA	**	NA

1/ Each value is the mean percentage of the short roots infected by each fungal symbiont of two seedlings from each of six replications per treatment.
2/ The difference between the treatment means of each combination of host and fungal symbiont was evaluated with the t test; ** denotes that the means differ at a level of significance of $P < 0.01$; NS denotes that the means do not differ significantly ($P > 0.05$); and NA denotes that the t test is not applicable.

Similar differences in growth were exhibited by the European alder seedlings, but the superiority of the seedlings inoculated with *P. tinctorius* reflected the greater development of *C. geophilum* ectomycorrhizae rather than a benefit derived from *P. tinctorius*. The total dry weight of the inoculated European alder seedlings was 88% greater than that of the control seedlings while the shoot/root ratio was 17% lower (Table 2). The benefit derived by the inoculated seedlings from the higher level of infection by *C. geophilum* was also reflected by the enhanced growth in height and root collar diameter (Table 3). The inoculated seedlings were 50% greater in height and 30% greater in root collar diameter than the control seedlings after three months, and 27% and 19% greater in height and root collar diameter, respectively, after six months. Subsequently, the volume of these seedlings was 120% greater than that of the control seedlings after three months and 81% greater after six months.

DISCUSSION

It is apparent that the inoculation of containerized sweet birch seedlings with a vegetative mycelial inoculum of *Pisolithus tinctorius* will promote sufficient ectomycorrhizal development to provide these seedlings a significant advantage over those grown by conventional methods. In this study, seedling weight, height, root collar diameter, and volume were significantly increased and the shoot/root ratio improved by the infection with this fungal symbiont in comparison with seedlings infected by naturally occurring ectomycorrhizal species. The adaptability of sweet birch and *P. tinctorius* to poor substrates, and the ability of *P. tinctorius* to form abundant ectomycorrhizae on this host which substantially increase its growth, suggest that this combination of host and symbiont has considerable potential for use in the reforestation of poor sites. This potential may be considerably enhanced by the additional advantages provided by containerization. It is probable that the only significant modification of standard nursery practices required for the successful infection of sweet birch by *P. tinctorius* other than the incorporation of the inoculum into a sterile potting medium is a reduction in the rate of fertilization, as high fertility has been demonstrated to retard the development of *P. tinctorius* ectomycorrhizae (Marx et al. 1977b, Ruehle 1980, Walker et al. 1982). It may be possible to achieve a higher level of infection of sweet birch with this symbiont by

Table 2.--The dry weights of containerized sweet birch and European alder seedlings inoculated with Pisolithus tinctorius and control seedlings after six months growth.?!

Treatment	Dry Weight (g) Shoot	Root	Total	Shoot/Root Ratio
----Sweet Birch----				
Inoculated	2.6	1.9	4.5	1.4
Control	2.1	1.1	3.2	2.0
Level of Significance2/	*	**	**	**
----European Alder----				
Inoculated	1.6	1.6	3.2	1.0
Control	0.9	0.8	1.7	1.2
Level of Significance2/	**	**	**	*

1/ Each value is the mean of two seedlings from each of six replications per treatment.
2/ The differences between the treatment means of each host were evaluated with the t teat; * and ** denote tbat the means differ at a level of significance of 0.01 < P < 0.05 and P < 0.01, respectively.

further reducing the rate of fertilization used in this study. Seedlings produced in this manner would not require the greenhouse growth period of six months used here to attain a size suitable for outplanting; four to five months would allow adequate growth to insure a favorable performance in the field.

It is probable that the development of Cenococcum geophilum ectomycorrhizae on the roots of the inoculated and control sweet birch seedlings in this study resulted from the presence of sclerotia in the peat moss portion of the potting medium, as this fungal symbiont ordinarily lacks the capacity to colonize new substrates via wind-borne propagules. The failure of the steam sterilization treatment to destroy the viability of these sclerotia can probably be attributed to a failure to adequately moisten the potting medium prior to sterilization, a factor compounded by an attempt to sterilize the potting medium in bulk quantities. The presence of Thelephora terrestris ectomycorrhizae on the roots of these seedlings resulted from the deposition of wind-borne propagules in the potting medium which originated in the pine stands that surround the greenhouse in which this study was conducted. Because P. tinctorius introduced in an inoculum has a demonstrated competitive advantage over T. terrestris occurring naturally when substrate nutrient levels are sufficiently low (Walker et al. 1982), the manipulation of this growth factor renders the possibility of competition resulting in a substantial reduction in the development of P. tinctorius ectomycorrhizae remote,

Table 3.--The growth of containerized sweet birch and European alder seedlings inoculated with Pisolithws tinctorius and control seedlings after three and six months.1/

Treatment	Three Months Height (cm)	Root Collar Dia (mm)	Volume (cm3)	Six Months Height (cm)	Root Collar Die (mm)	Volume (cm3)
----Sweet Birch----						
Inoculated	29.4	2.6	2.2	51.3	5.1	13.3
Control	26.0	2.0	1.2	42.5	4.3	8.1
Level of Significance2/	**	**	**	**	**	**
----European Alder----						
Inoculated	15.7	2.6	1.1	24.0	5.1	6.7
Control	10.5	2.0	0.5	18.9	4.3	3.7
Level of Significance2/	* *	**	**	**	**	**

1/ Each value is the mean of six replications of 25 seedlings each per treatment.
2/ The differences between the treatment means of each host were evaluated with the t test; ** denotes that the means differ at a level of significance of P < 0.01.

particularly when the potting medium is adequately sterilized prior to the incorporation of the P. tinctorius inoculum.

The superior performance of the European alder seedlings inoculated with P. tinctorius in comparison with the control seedlings can not be attributed to this fungal symbiont, as the isolate of P. tinctorius used in this study did not form ectomycorrhixae on any of the European alder seedlings examined. It is probable that P. tinctorius is physiologically incompatible with European alder, given past failures at inducing a symbiotic association involving this fungus and host (Molina 1981, Walker et al. 1982); and any attempt to effect such a relationship using routine methods of inoculation will prove unsuccessful. It can be concluded that the higher level of infection by C. geophilum is the factor accountable for the improved growth of the inoculated seedlings. C. geophilum is a known ectomycorrhixal symbiont of European alder (Trappe 1962) and offers the additional advantage of being adaptable to a broad range of adverse growing conditions, including drought and high substrate temperatures (Trappe 1977). As the potential of European alder as a reclamation species on adverse sites is partially compromised by its intolerance of drought (Vogel 1981, Walker et al. 1982), the inoculation of this host with C. geophilum prior to outplanting may prove to be a valuable technique to insure an acceptable seedling performance during extended dry periods, given the ability of an ectomycorrhizal association to facilitate the absorption of water by the host (Bowen 1973, Dixon et al. 1980, Duddridge et al. 1980, Goss 1960, Theodorou and Bowen 1970, Walker et al. 1982). The significantly greater development of C. geophilum ectomycorrhisae on the roots of the European alder seedlings inoculated with P. tinctorius in comparison with the control see& lings can probably be attributed to residual nutrients in the P. tinctorius inoculum which stimulated the growth of C. geophilum in excess of that which occurred in the absence of these nutrients. For both the inoculated and the control seedlings, the origin of the C. geophilum infection was the sclerotiapresent in the peat moss portion of the potting medium, as discussed above.

The final and most important consideration in evaluating the potential benefits of an induced mycorrhixal association is the performance in the field of inoculated seedlings in comparison with noninoculated controls. As the benefits provided the host by an ectomycorrhizal infection are often most pronounced under poor growing conditions, outplantings on adverse sites are most pertinent for making these comparisons. The feasibility of implementing procedures to inoculate containerized sweet birch and European alder seedlings with an appropriate ectomycorrhizal symbiont will be dependent upon the conclusions drawn from such studies. The results of this study indicate that the inoculation of contafnerixed sweet birch with P. tinctorius offers a viable method of producing superior seedlings for outplanting on harsh substrates. This potential is augmented by the availability of commercial P. tinctorius inoculums (Marx and Kenney 1982, Marx et al. 1982). There is also some indication that the inoculation of containerized European alder with C. geophilum may provide this species with substantial advantages upon outplanting, but the enthusiasm for this combination of host and symbiont is tempered by the lack of a readily available source of inoculum, and C. geophilum is known for its slow growth in-pure culture (Marx and Kenney 1982). Also, a recent attempt by Molina (1981) to induce an ectomycorrhizal association between C. geophilum and European alder using pure culture techniques proved unsuccessful, indicating a need for further investigation into the ectomycorrhixal specificity of this host before large scale inoculations become feasible. Continuing efforts to improve upon the methods of producing these seedlings and to evaluate their performance on adverse sites are currently in progress.

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EFFECT OF BIFENOX AND OXYFLUORFEN ON EMERGENCE AND MORTALITY OF LOBLOLLY SEEDLINGS UNDER GROWTH CHAMBER CONDITIONS"

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Abstract .--The relative phytotoxicity of three formulations of bifenox and oxyfluorfen on emergence and subsequent mortality of loblolly pine (*Pinus taeda* L.) seedl ings was investigated in growth chamber studies. Emergence was not inhibited by either 120 mg/kg of bifenox or 20 mg/kg of oxyfluorfen regardless of formulation tested. No significant interaction with herbicide treatment was observed for 1) stratification; 2) seed size; 3) sowing depth; or 4) temperature. All herbicide treatments increased seedling mortality. Mortality was greater with 20 mg/kg of oxyfluorfen than with 120 mg/kg of bifenox. Mortality in controls was 32% while in herbicide treatments mortality ranged fran 46 to 63%. The greatest mortality occurred with the oxyfluorfen emulsifiable concentrate which also produced "white lesions" on seedling hypocotyls.

INTRODUCTION

Bifenox and oxyfluorfen have been tested in southern pine nurseries for several years with promising results. Bifenox was first tested on loblolly pine in 1974 and has been effective in controllim a number of broadleaf weeds. Handweeding times were significantly reduced with no significant reduction in the number of plantable seedlings (South et al. 1978). Gxyfluorfen was first tested on loblolly in 1976, and was effective in controlling both grasses and broadleaf weeds (South and Gjerstad 1980). For that reason, weed control obtained with oxyfluorfen was often better than with bifenox at pine nurseries with high populations of grasses. Oxyfluorfen showed no significant reduction in plantable seedlings when compared with hand-weeded controls. Using data supplied by the Auburn University Southern Forest Nursery Management Cooperative (AUSFNMC), the Environmental Protection Agency registered bifenox in 1977 and oxyfluorfen in 1978 for use in southern pine nurseries. Since 1978, southern nurserymen have used these herbicides extensively in pine seedbeds both as preemergence and postemergence treatments.

Nurserymen reported no problems with preemergence applications of these herbicides fran 197'7 to 1980. In 1981, however, nurserymen at five locations reported "'white lesion" occurrence on newly-merged loblolly seedlings and sane seedling death. Several nurseries were visited to ascertain the cause of the lesions. Possible causes considered included herbicides, sun scald, wind burn, sand burn, and pathogens, but no consensus as to the cause was reached. Gxyf luorfen had been used as a preemergence herbicide at all the affected nurseries. However, lesions were also observed on areas where bifenox had been used as well as on plots where herbicides were not directly applied.

Two growth chamber studies were conducted to determine the effects of oxyfluorfen and bifenox on establishment of loblolly pine. The objectives of the studies were to determine: 1) the effects of different formulations of oxyfluorfen and bifenox on emergence, mortality and lesion formation of loblolly pine; 2) whether rate of germination affected herbicide injury; and 3) whether temperture or depth of sowing could affect herbicide injury.

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MATERIALS AND METHODS

Experiment 1

Loblolly seeds were obtained from the Hammermill Paper Company seed orchard in Selma, Alabama. The seeds were sized and two groups (small and jumbo) were selected for study. Half of the seeds from each size group were soaked in cold water for 24 h before sowing. Sixty milk cartons (7 by 7 by 10 cm) were each filled with 350 g of loamy sand. Twenty-five seeds were sown in each, container and covered with an additional 50 g of either herbicide-treated or nontreated soil. All treatments were replicated five times. Treated soil was prepared from stock solutions of herbicides. The stock solutions were:

a. bifenox emulsifiable concentrate - 1 ml cannercial grade (21% active ingredient) in 60 ml distilled water.
b. oxyfluorfen emulsifiable concentrate - 1 ml commercial grade (23.5% active ingredient) in 60 ml distilled water.

A herbicide concentration of 20 mg/kg was prepared by adding 6.0 ml of herbicide solution to 1.2 kg of a loamy sand soil which had been screened and air dried.1 On August 18, 1981, the cartons were placed in a growth chamber set for a 12 h day cycle with a 27 C day temperature and a 16 C night temperature. Relative humidity of the chamber was approximately 70%. A combination of fluorescent and incandescent lights provided an intensity of 274 uE $sec^{-1}m^{-2}$. Cartons were watered as needed with 50 ml of water. Seedling emergence was recorded on September 3 and again on September 16. Bypocotyl height, seedling mortality, and the number of lesions were also recorded on September 16. Analysis of variance was conducted using a 3 by 2 by 2 factorial design. Data for surviving seedlings, mortality, and lesions were expressed as a percentage of germinated seedlings.

Experiment 2

Loblolly seeds were obtained from the Weyerhaeuser Company seed orchard near Magnolia, Arkansas. @e-hundred sixty-eight plastic germination trays (10 by 10 by 4 cm) were each filled with '350 g of soil. Each container was sown with 50 seed. Half of the containers were sown before the addition of 50 g of treated (or nonteeated) soil while the remaining half were surface sown after the 50 g of soil had been added, All treatments were replicated four times, Treated soil was prepared with stock solutions of herbicides. The stock solutions were:

a. bifenox technical - 0.8246 g (97% active ingredient in 10 ml of acetone added to 190 ml of distilled water.
b. bifenox emulsifiable concentrate - 2 ml cannercial grade (21% active ingredient) in 120 ml of distilled water.
c. bifenox wettable powder - 1 g cannercial grade 80% active ingredient) in 200 ml of distilled water.
d. oxyfluorfen technical - 0.563 g (71% active ingredient in 10 ml of acetone added to 90 ml of distilled water.
e. oxyfluorfen emulsifiable concentrate - 1 ml cannercial grade (23.5% active ingredient) in 60 ml of distilled water.
f. oxyfluorfen wettable powder - 1.6 g commercial grade (21% active ingredient) in 100 ml of distilled water.

Concentrations of oxyfluorfen at 20 mg/kg were prepared by adding 4.5 ml of the stock solutions to 900 g of a loamy sand soil which had been dried and screened. Bifenox concentrations of 120 mg/kg were prepared by adding 27 ml of the stock solutions to 900 g of soil. Water was added to bring the soil to field capacity. The containers were placed in three growth chambers on December 17, 1981. The temperature settings of the chambers were (1) 24 h at 17 C, (2) 24 h at 21 C, (3) 12 h at 21 C and 12 h at 17 C. Fluorescent light provided an intensity of 8 to 16 uE $sec^{-1}m^{-2}$. Emergence and mortality of seedlings were recorded at 2 to 3 day intervals from December 22 to January 25. Analysis was conducted using a 7 by 3 by 2 factorial design. Data for lesions and mortality were expressed as a percentage of emerged seedlings. Data for germination and surviving seedlings were expressed as a percentage of seeds planted. Analysis of variance was performed using an arcsine transformation of the percentage data.

RESULTS

Experiment 1

The pregermination cold-water treatment, seed size, and herbicide treatment significantly affected seedling emergence 16 days after sawing (Table 1). The pregermination treatment had the greatest effect on the rate of emergence. Seeds receiving the 24 h cold soak averaged 32% emergence while nontreated seeds averaged only 12% emergence. Seed size was the next most influential factor. Emergence of small seed was greater than that for jumbo seed. However, an interaction occurred between seed size and pregermination treatment. The cold soak had a greater effect on small seed than on jumbo seed. Herbicide treatment accounted for only seven percent of the modeled variation. Emergence of seedlings in herbicide treated soil was greater than the control (Table 2).

Table 1.—Analysis of variance of variables in Experiment 1.

Source	d.f.	16th Day Germination Sum of sq.	16th Day Germination Prob. of>F	29th Day Germination Sum of sq.	29th Day Germination Prob. of>F	Standing Sum of sq.	Standing Prob. of>F	Mortality Sum of sq.	Mortality Prob. of>F	Lesions Sum of sq.	Lesions Prob. of>F	Height Sum of sq.	Height Prob. of>F
Replication	4	0.035	0.2519	0.048	0.4450	0.030	0.7618	0.019	0.9133	0.025	0.1525	0.98	0.1807
Herbicide	2	0.049	0.0269	0.039	0.2275	0.465	0.0001	0.869	0.0001	1.371	0.0001	33.12	0.0001
Seed size	1	0.150	0.0001	0.240	0.0001	0.150	0.0037	0.011	0.4522	0.017	0.0303	4.21	0.0001
cold soak	1	0.400	0.0001	0.417	0.0001	0.365	0.0001	0.009	0.5110	0.001	0.5722	0.79	0.0262
Herbicide x seed size	2	0.002	0.8241	0.039	0.2275	0.109	0.0413	0.067	0.1951	0.048	0.0027	0.31	0.3608
Herbicide x cold soak	2	0.039	0.0527	0.039	0.2301	0.031	0.3823	0.003	0.9342	0.002	0.7632	0.82	0.0762
Seed size x cold soak	1	0.034	0.0249	0.049	0.0557	0.006	0.5428	0.034	0.1989	0.044	0.0010	0.23	0.2240
Herbicide x seed size x cold soak	2	0.013	0.3654	0.013	0.6004	0.006	0.8354	0.053	0.2770	0.091	0.0001	1.59	0.0686
Error	44	0.275	—	0.561	—	0.702	—	0.875	—	0.156	—	6.60	—
Corrected Total	59	0.999	—	1.447	—	1.086	—	1.940	—	1.757	—	48.67	—

Table 2.--Effect of bifenox and oxyfluorfen on merging loblolly pine seedlings in a growth chamber.

Treatment	Rate (mg/kg)	Seed size	Cold soak	16th Day Germination (%)	29th Day Germination (%)	Standing (%)	Mortality (%)	Lesions (%)	Height (cm)
Control	0	Small	Yes	36.8	72.0	65.6	10.5	0	3.72
Control	0	Large	Yes	12.0	55.2	50.4	8.4	0	4.04
Control	0	Small	No	11.2	57.6	52.0	10.9	8	3.74
Control	0	Large	No	8.8	36.7	32.8	11.7		4.16
Oxyfluorfen	20	Small	Yes	40.0	56.0	36.8	33.3	33.6	1.88
Oxyf lourfen	20	Large	Yes	29.0	58.4	38.4	34.3	28.6	2.69
Oxyfluorfen	20	Small	No	19.2	53.6	26.4	50.4	18.6	1.96
Oxyfluorfen	20	Large	No	8.0	39.2	28.8	25.8	47.5	1.88
Bifenox	20	Small	Yes	48.0	72.8	68.0	6.3	1.0	3.34
Bifenox	20	Large	Yes	33.6	66.4	57.6	13.5	0	3.90
Bifenox	20	Small	No	14.4	56.8	51.2	10.4	1.2	2.92
Bifenox	20	Large	No	8.0	36.0	32.0	11.7	0	3.80

Seedling emergence was near completion 29 days after sowing (Table 2). The pregermination treatment and seed size effect were still significant. The greatest emergence was still observed for small seed that received the pregermination cold-water treatment while the non-treated jumbo seed were still the lowest in emergence. Herbicide treatments at this stage of development were no longer significantly affecting seedling emergence.

Herbicide treatment had a significant effect on seedling mortality. Seedlings in soil with 20 mg/kg of oxyfluorfen had merged but weakened stems resulted in seedlings falling over. Mortality of seed1 ings treated with oxyfluorfen was over three-times greater than that of the control or the bifenox treatments. There was no significant difference in mortality between the bifenox treatment and the control. Neither seed size nor the pregerminat ion treatment affected seedling mortality.

Height of the hypocotyl was affected by herbicide treatment. The bifenox treatment did not significantly reduce height growth but the oxyfluorfen reduced hypocotyl height by 45%. Seed size and the pregermination treatment also affected hypocotyl height. On the average, hypocotyls of seedlings fran jumbo seed were about 0.5 cm taller than small seed but hypocotyls fran seed treated with the cold soak were only slightly taller than those fran non-treated seed. A significant interaction was observed between herbicide treatment, seed size, and pregerminat ion treatment. The pregermination treatment, had no effect on hypocotyl height except for jumbo seed in oxyfluorfen soil. Seedlings fran this treatment had hypocotyls that were approximately 1 an taller than those fran non-treated jumbo seed in oxyfluorfen soil.

The oxyfluorfen treatment produced "white lesions" at the base of the hypocotyl on 30% of the merged seedlings. No lesions were observed on the controls and only two of 290 seedlings in the bifenox treatment had lesions.

Experiment 2

Depth of saving was by far the factor most affecting energence. Sowing depth was significant at the 0.0001 level for all dates (analyses for three dates are presented in Table 3). Covering the seed with soil reduced emergence by approximately 25% (Fig. 1).

An interaction between temperature and depth existed during the first 11 days after sowing. During this early germination phase, the 21 C temperature increased emergence of surface sown seed more so than covered seed. Rate of energence was significantly different for the three temperature regimes over the first 16 days. Emergence was faster with constant 21 C and slowest with constant 17 C.

Fran 22 days after sowing until the end of the experiment, a depth by temperature interaction occurred. For the surface-sown treatments, emergence had neared canpletion. With covered seed, however, temperature still had an effect but now the higher temperature decreased energence. Herbicide treatment did not significantly affect seedling emergence (Fig. 2).

Table 3.—Analysis of variance of variables in Experiment 2.

		14th Day				22nd Day				32nd Day			
		Germination		Mortality		Germination		Mortality		Germination		Mortality	
Source	d.f.	Sum of sq.	Prob. of>F	Sum of sq.	Prob. of>F	Sum of sq.	Prob. of>F	Sum of sq.	Prob. of>F	Sum of sq.	Prob. of>F	Sum of sq.	Prcb. of>F
Replication	3	0.057	0.5822	0.012	0.6181	0.099	0.0162	0.131	0.0046	0.055	0.1473	1.295	0.0001
check vs bifenox	1	0.053	0.1777	0.009	0.2318	0.004	0.4978	0.179	0.0001	0.000	0.9896	0.496	0.0032
check vs oxyfluorfen	1	0.003	0.7317	0.000	0.9563	0.005	0.4567	0.073	0.0064	0.020	0.1635	1.065	0.0001
bifenox vs oxyfluorfen	1	0.959	0.1549	0.017	0.1074	0.036	0.9456	0.047	0.0295	0.940	0.0476	0.225	0.9430
W P vs E C	1	0.101	0.0632	0.000	0.6696	0.010	0.2986	0.022	0.1280	0.022	0.1422	0.098	0.1793
tech vs E C	1	0.023	0.3745	0.021	0.0711	0.000	0.8780	0.005	0.4769	0.001	0.7644	0.005	0.7566
tech vs W P	1	0.028	0.3274	0.025	0.0523	0.013	0.2317	0.048	0.0265	0.014	0.2416	0.058	0.2992
Temperature	2	1.245	0.9001	0.031	0.0920	0.640	0.1164	0.249	0.0001	0.129	0.0023	3.903	0.0001
Depth of sowing	1	14.999	0.0001	0.333	0.0001	4.659	0.0001	0.712	0.0001	3.269	0.0001	1.969	0.0001
Herbicide x temperature	12	0.380	0.3681	0.016	0.9977	0.116	0.4111	0.156	0.1811	0.111	0.5395	0.343	0.8907
Herbicide x depth	6	0.069	0.8790	0.022	0.7574	0.457	0.5527	0.071	0.2693	0.020	0.9195	0.245	0.6044
Temperature x depth	2	0.674	0.2834	0.021	0.2032	0.058	0.0459	0.040	0.1296	0.254	0.0009	0.292	0.0704
Herbicide x depth x temperature	12	0.225	0.7955	0.093	0.2910	0.647	0.9500	0.169	0.1405	0.066	0.6953	0.421	0.7932
Error	123	3.549	—	0.794	—	1.137	—	1.170	—	1.249	—	6.614	—
Corrected Total	167	29.793	—	1.390	—	6.464	—	2.939	—	5.136	—	16.332	—

Depth of planting not only influenced emergence but also mortality (Pig. 3). Covering seed with soil reduced mortality by approximately 16%. An interaction between temperature and depth occurred between the 16th and 27th day after sowing. The 21 C temperature increased seedling mortality of surface sown seed more so than covered seed.

After the first 3 weeks, both bifenox and oxyfluorfen increased seedling mortality (Fig. 4). Ranking of herbicide treatments varied fran day to day but after the 29th day, the emulsifiable concentrate and technical grade of oxyfluorfen caused the greatest mortality. Luring the 20th to 25th day, mortality was less with wettable powder formulations than with technical formulations.

The percentage of seedlings that remained standing was a function of percent emergence and seedling mortality. Since there was little mortality over the first 13 days, the analyses for percent emergence and percent standing seedlings were very similar. During the first 22 days, depth of sowing was the most influential factor affecting standing seedlings (Fig. 5). However, with time, depth of planting became less important. At the end of the experiment (from the 34th to 39th day) sowing depth was the least important factor. Temperature had become more influential. Over the first 18 days of the experiment, the warmer temperatures had more standing trees but after the 29th day, more seedlings were standing in the cooler temperatures.

Both herbicides reduced the number of standing seedlings during the latter stages of the experiment (Fig. 6). From the 22nd to the 25th day, the percentage of standing seedlings was lowest for the emulsifiable concentrate and technical grades of bifenox. On the 34th day, all but the wettable powder formulations were significantly different from the control. By the final day, the emulsifiable concentrate and technical grades of oxyfluorfen were the only treatments significantly lower than the controls.

Herbicide treatment was the only factor to affect the formation of lesions. The emulsifiable concentrate of oxyfluorfen was the only treatment that was significantly different ($pr>F$ = 0.02) from the controls. At the end of the study, this treatment produced lesions on 5.6% of the emerged seedlings.

DISCUSSION

The rates of bifenox used in the two studies differed. The first study indicated that at equal concentrations (20 mg/kg) oxyfluorfen was more injurious than bifenox to loblolly pine. In the nursery, however, the preemergence rate of bifenox is normally six times that of oxyfluorfen. Therefore, the rate of bifenox was increased to 120 mg/kg in the second study for a more realistic comparison of the two herbicides. A concentration of 20 mg/kg in the top 0.6 cm of soil is equivalent to 1.56 kg/ha (assuming a soil bulk density of 1.3 g/cc). This would be approximately equal to a 3X rate of oxyfluorfen. Likewise, 120 mg/kg would be approximately equal to a 3X rate of bifenox. A soil depth of 0.6 cm was used because bifenox and oxyfluorfen remain near the soil surface and are not readily leached (Fadayomi and Warren 1976, Weed Science Society of America 1979). Results fran the second study indicated that oxyfluorfen at 20 mg/kg resulted in more seedling mortality than bifenox at 120 mg/kg.

While these herbicides caused mortality in these tests, they did not impact seedling emergence. Other factors such as depth of sowing, temperature, seed size, and pregerminat ion treatment did dramatically affect emergence. There was no consistent interaction between herbicide treatment and other factors which affected rate of emergence.

In the spring of 1981, germination of loblolly seed was delayed at several nurseries due to cool, wet, and cloudy conditions. It is possible that slow emergence in the presence of these herbicides resulted in the injury observed in 1981. Injury had not previously been observed (1978 to 1980) when weather conditions were more favorable for germination. If germination was slowed, the period of time in which the emerging seedling would be in contact with the herbicide-treated soil would be extended and this could result in more injury. Although results from these growth chamber studies should not be considered conclusive, they did indicate that herbicidal injury from oxyfluorfen or bifenox was not greater as a result of slow germination.

Herbicide treatment had a negligible effect on seedling performance during the first 3 week period. Herbicide effects became more apparent during the fourth and fifth weeks. This stage of seedling development has been referred to by Baker (1950) as the "succulent stage". Our observations indicate that bifenox and oxyfluorfen cause damage to seedlings during this succulent stage.

At the end of the period of succulence, the cortex collapses and a hard "bark" is formed. This collapse occures 3 to 4 weeks after the seedling appears aboveground and about the time the first true leaf reaches one-half the length of the cotyledons (Baker 1950). Injury from preemergence applications of oxyfluorfen or bifenox apparently does not occur after the cortex collapses.

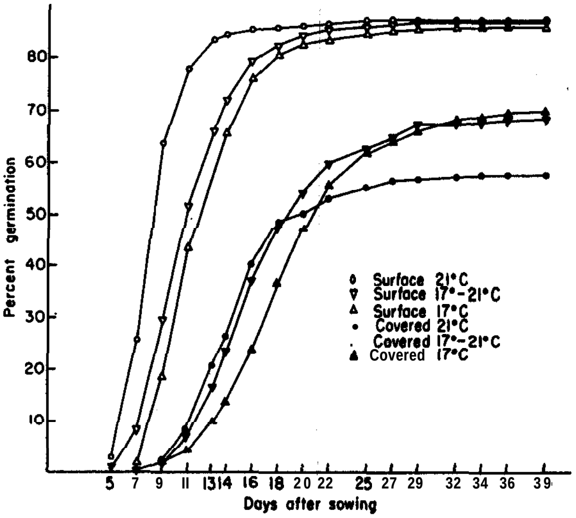

Figure 1.--Effect of sowing depth and temperature on emergence of loblolly pine seedlings.

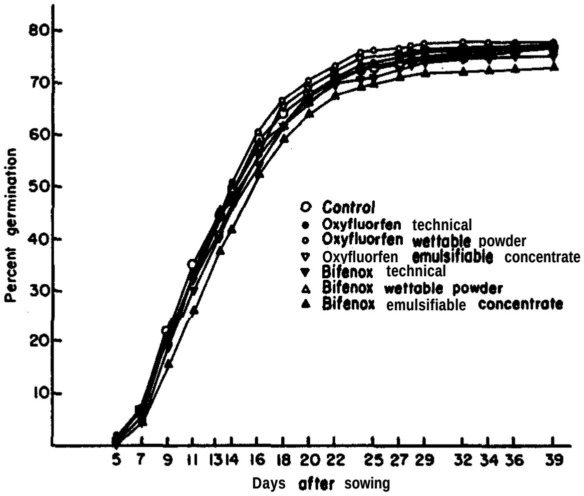

Figure 2. Effect of formulation on emergence of loblolly pine seedlings.

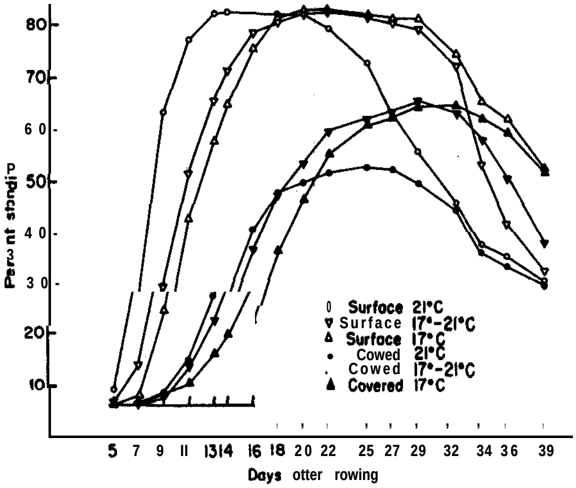

Figure 3.--Effect of saving depth and temperature on mortality of loblolly pine seedlings.

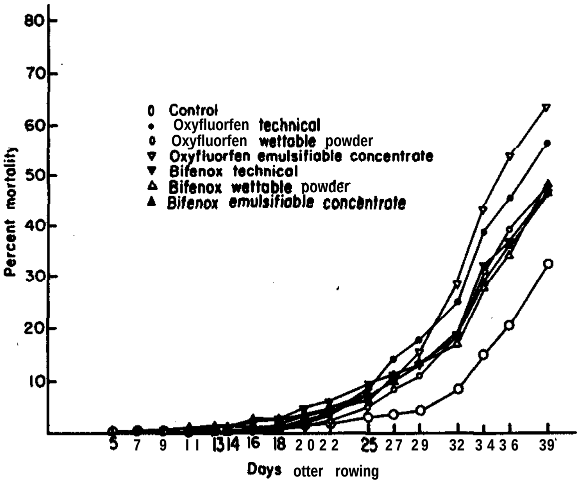

Figure 4.--Effect of fomlation on mortality on loblolly pine seedlings.

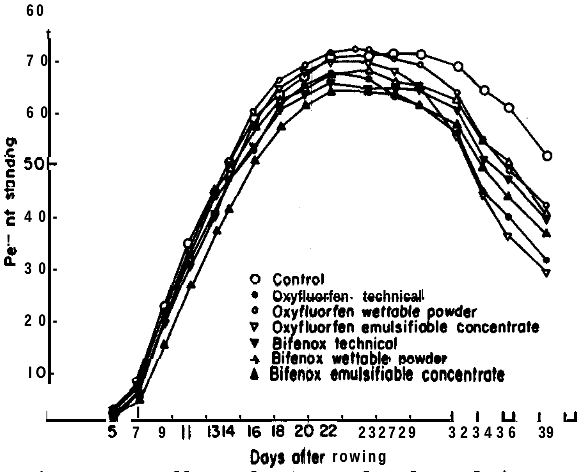

Figure 5.--Effect of sowing depth and temperature on survival of loblolly pine seedlings.

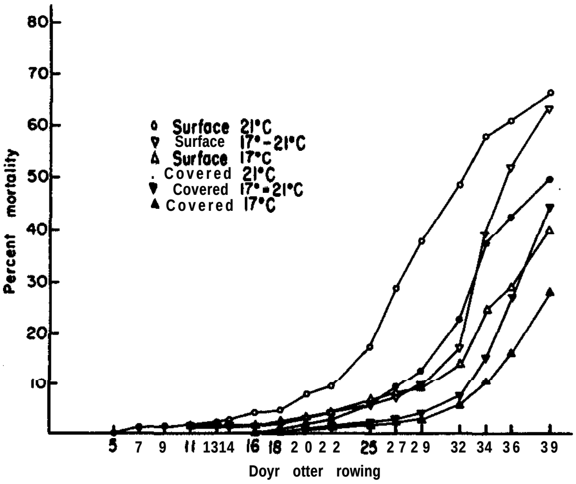

Figure 6.--Effect of fomlation on survival of loblolly pine seedlings.

Nurserymen have described injury symptoms as being very similar to "heat lesions." Wakeley (1954) described fresh heat lesions as "characteristically pale and sharply defined, and are at or just above the soil surface and do not extend below it." Hartley (1918) described in detai 1 the format ion and occurrence of "white spot" lesions on ponderosa (*Pinus ponderosa* Laws.) seed1 ings. He concluded that formation of lesions was a result of excessive heat.

Recent results fran growth chamber 'studies indicate that bifenox can also produce lesions on loblolly pine seedlings[3/]. Lesions caused by bifenox or oxyfluorfen can occur on any side and at any point on the hypocotyl but do not extend to the cotyledons. Most lesions occur on one side of the hypocotyl and are often near the soil line. In sane cases, the lesions encircle the hypocotyl. Lesions disappear when the "bark" is formed 3 to 4 weeks after emergence. Seedl ings with lesions often survive and grow normally. Seedlings that die are usually those that have fallen over (due to constriction of the hypocotyl) *or* are those that are weakened and lack the strength to lift the testa and cotyledons out of the soil.

The original premise that herbicidal injury was exacerbated by factors which delayed emergence could not be demonstrated in these tests. However, it is possible that sensitivity to these herbicides is a function of 1 ight intensity rather than cool temperatures. Low light intensities reduce the production of epicuticular wax (Martin and Juniper 1970), and wax thickness is negatively correlated with oxyfluorfen damage in sweetgum (South 1982). It is possible that cloudy weather during the seedling emergence phase could result in thin epicuticular wax layers which could result in increased sensitivity to certain diphenylether herbicides.

Evidence from field crops indicate that a herbicide similar to oxyfluorfen can cause injury when these conditions occur (Gates 1972, Pollak and Crabtree 1 976). Light intensity during emergence apparently plays a significant role in the action of fluorodifen (p-ni trophenyl α,α,α-trifluoro-2-ni tro-p-tolyl ether) which causes lesions to form on hypocotyls of soybeans [*Glycine max* (L.) Merr. var. "Bragg"] and green beans (*Phaseolus vulgaris* L. 'Tendercrop'). Results from these studies indicated that low light intensities after a preemergence application of fluorodifen followed by higher light intensities' at the time of crop emergence, or shortly thereafter, increased the probability of crop injury. Similar studies should be conducted with loblolly to determine whether light intensity during emergence can affect the formation of lesions caused by diphenylether herbicides.

Experiment 1 demonstrated that 3X rates of oxyfluorfen can decrease hypocotyl height of loblolly. Field results have indicated that both oxyfluorfen and bifenox can reduce early height growth. Significant reductions in hypocotyl height occurred with IX rates of bifenox and 2X rates of oxyfluorfen (Table 4).

Experiment 2 demonstrated that 3X rates of bifenox and oxyfluorfen can increase mortality of loblolly during the succulent stage. Observations at several nurseries and field tests indicated that 1X rates of these herbicides can increase mortality 5 to 10% during this stage of development. This seams at first to conflict with earlier field data that reported no significant reduction in plantable seedlings (South et al. 1978, South and Gjerstad 1980). In addition to differences in environmental conditions, several factors can explain why injury was not detected earlier.

Weed control tests were often established in areas wi th high weed populations. Competition and handweeding injury muld of ten cause hand-weeded control plots to produce fewer seedlings than herbicide treated plots. Seedling reductions during the succulent stage of five to eight percent could have occurred in the herbicide plots but would not be noticed if 10 to 25% reductions occurred in the control plots. For this reason, increases in plantable seedlings on plots treated with bifenox or oxyfluorfen were always observed at nurseries where total weeding times for controls exceeded 4 min/m^2 (Table 5).

Variation within seedbeds at most nurseries is too great to detect differences in density of 10% or less with 4 replications of 200 to 300 seedlings. The percent reduction needed to be significant (using L.S.D. at the five percent level) ranged fran 13 to 63% (at nurser ies where controls required less than 4 min/m^2 of hand-weeding)(Table 5). Reducing the significance level to the 10% level would be of little benifit since detectable differences would still be greater than a 10% reduction. An increase in sample size or an increase in replications would be needed in order to guard against accepting the null hypothesis when in fact the alternative hypothesis is true (making a Type II error) (Steel and Torrie 1960). At sane nurseries however, 200 or more samples are needed in order to determine the seedling production for sane seed lots within an accuracy of plus or minus five percent. For this reason, herbicide tests should be installed at nurseries where variation in seed1 ing density is kept to a minimum. Nurseries having both precision sowing and low weed populations would be the most likely candidates.

[3/] Personal communication, Bill Carlson, Weyerhaeuser Cb., Hot Springs, AR 71901;

Herbicide-induced injury of the magnitude reported by nurseries is an excellent example of a factor that may not be statistically significant but may well be economically significant. For a nursery producing 50 million seedlings, a five percent reduction in plantable seedlings can mean a loss of $50,000. Therefore, the decision to use a herbicide which is potentially 'injurious has to be carefully considered. The decision should be based on the risks versus the benefits. At nurseries with high weed populations, use of bifenox or oxyfluorfen will offer more benefits which will more than offset the risks. However, at nurseries with low weed populations, use of these herbicides could result in more injury than would other alternatives. Herbicide regimes that carbine safer but perhaps less effective preemergence herbicides with effective postemergence herbicides need to be tested.

Table 4.--Effect of preemergence applications of bifenox and oxyfluorfen on emerging loblolly pine seedlings at the Ft. Towson Nursery in 1981.

Treatment	Application rate	25th Day after sowing[1/] Expt. 1 Seedling density	Expt. 1 Seedling height	Expt. 2 Seedling density	Expt. 2 Seedling height
	(kg/ha)	(No./m²)	-(cm)-	(No./m²)	-(cm)-
Control	0	412 a	4.9 a	382 a	5.1 a
Bifenox	3.4	374 a	4.3 b	390 a	4.6 bc
Cxyfluorfen	0.56	390 a	4.8 a	390 a	4.8 ab
Cxyfluorfen	1.12	379 a	4.2 b	374 a	4.2 c

1/Means within each column followed by the same letter are not significantly different at the 5% level as judged by Duncan's Multiple Range test.

Table 5.-- Effect of field applications of bifenox and oxyfluorfen on seedling production of loblolly pine[1/].

Nursery	State	year	Handweeding time for controls	Plantable seedlings in controls	Difference bifenox 3.4 kg/ha	Difference oxyfluorfen 0.6 kg/ha	Change Required for 5% level	L.S.D. at 10% level
			(min)	(No./m²)	(%)		(%)	
Weyerhaeuser	AK	78	173	-12	+11	34	28	34
Weyerhaeuser	NC	78	0.5	191	+25	+ 4	27	22
Baucum	AR	74	0.6	301	-19	—	16	13
Columbia	LA	75	0.6	170	+76	--	57	47
Baucun	Au	77	1.1	61	-33	-7	63	52
Baucum	AK	75	1.7	245	-14	--	27	22
Miller	AL	76	3.2	136	+18	--	25	21
Clar idge	NC	74	3.3	266	+ 3	--	22	18
Columbia	LA	74	3.4	178	-23	—	19	16
Ti lghman	SC	74	3.4	286	-14	--	22	18
Baucun	AR	79	3.6	145	+11	+27	27	22
Waynesboro	MS	74	8.5	205	+16	--	13	11
Kentucky Dam	KY	76	10.2	110	+134	+180	70	58
Coastal	SC	75	11.4	222	+ 6	--	17	14
Clar idge	NC	75	11.5	364	+ 5	--	13	11
Kentucky Dam	Ky	77	12.9	3	+1660	+2874	1510	1258
Baucum	AU	78	14.7	29	+72	+72	124	103
Great Southern	SC.	77	22.0	88	+130	+106	55	46
Coastal	SC	76	27.9	164	t16	+16	22	18
Westvaco		77	38.1	174	+10	+30	28	23

1/ Data from six Auburn University Southern Forest Nursery Management Cooperative Annual Reports.

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FIELD RESISTANCE OF SLASH PINE FAMILIES AFFECTED BY INTERACTIONS WITH LOCAL RUST POPULATIONS

Harry R. Powers, Jr.[1/] and Marvin Zoerb[2/]

Abstract.--Progeny of a rust-resistant slash pine selection maintained their resistance when planted at several locations in Georgia, including the high rust hazard area of Houston County. However, one planting in Baldwin County suffered heavy losses from rust. Artificial inoculation tests confirmed that the general rust population in that county was highly virulent on this one family. Additional inoculations, using rust collections from the progeny of another resistant selection, demonstrated sharply increased virulence when reinoculated on seedlings of the same family. This increased virulence was also evident on seedlings of the parent from which this selection derived its resistance. This information indicates that consideration must be given to sources of resistance and the possibility of geographic variation in rust pathogenicity when deploying rust resistant pines.

INTRODUCTION

Fusiform rust, caused by Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme, is by far the most serious disease of loblolly (Pinus taeda L.) and slash (Pinus elliottii Englem. var. elliottii) pines, with losses due to product degrade alone estimated at $75 million annually (Powers et al. 1981). Southern foresters generally agree that disease resistant pines offer the best hope for reducing the tremendous losses inflicted by fusiform rust (Schmidt et al. 1981). With other rust diseases on agronomic crops, resistance in host plants is not static, but must be continually adjusted in relation to constantly shifting populations of the pathogen. Studies dealing with pathogenic variability of the fusiform rust pathogen on both slash and loblolly pines have demonstrated extensive variation (Snow et al. 1975, Powers et al. 1977). Also, rust spores collected from infected members of resistant families (family-specific isolates) are more virulent than the general rust population when used to reinoculate seedlings of the same family. While such isolates have shown higher levels of virulence on certain families of both slash (Snow et al. 1976) and loblolly pine (Powers et al. 1978), increases in virulence on specific slash pine families have been more dramatic. Most studies on variation within the overall population of this organism have been done by collecting samples of aeciospores from individual rust galls, and then inoculating seedlings of open-pollinated families of pines with these isolates. Thus, evidence of variability in pathogenicity has been based primarily on artificial inoculations rather than on results from field tests.

The study described here was started when a resistant family of slash pine (10-226) became heavily infected in Baldwin County, Georgia. In 10 other field plantings at locations in eastern Georgia, this family averaged less than half the infection of the test means. The primary objective of the study was to determine if the rust population in the Baldwin County area was more virulent on family 10-226 than rust collections from another area where this family had maintained its resistance. Secondary objectives were (1) to determine if family-specific isolates from families 10-226 and 2903-1 would prove to be more virulent on those families than the general rust population, and (2) to compare the response

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[2/] Project Leader, Tree Improvement, Union Camp Corporation, Rincon, Ga., 31326 of family 2903-1 with that of the parental selection (Jones 14) from which it derived its resistance when inoculated with a family-specific isolate from 2903-l.

MATERIALS AND METHODS

Seeds of 12 open-pollinated slash pine families were used in this study. Seeds of family 10-226 were collected in the seed orchard of the Union Camp Corporation, Rincon, Georgia. Those for all other numbered families were collected from the U.S. Forest Service rust-resistant clone bank in Houston County, Georgia. The slash pine check seeds were from a bulk lot collected from several rust-infected slash pine trees in the same county. Two rust collections representing the general populations of the pathogen in Houston and Baldwin Counties were made by sampling 8 individual galls at random from each location in plantings of nursery-run slash pine seedlings. Two family-specific collections were made, each comprised of aeciospores collected from 8 rust galls on trees of that specific family. Spores from trees of 2903-1 were collected in Houston County, and those from 10-226 in Baldwin County. Aeciospores from the 8 galls of each source were mixed on an equal volume basis to provide the four composite isolates.

Seedlings of northern red oak (Quercus ruba L.) were inoculated with aeciospores from each collection. Basidiospores were harvested after 3 weeks and used for pine inoculations (Matthews and Rowan 1972). Seeds from each of the 12 families were germinated and seedlings transplanted into eight flats containing 20 seedlings each. After 6 weeks the seedlings were inoculated by spraying with a suspension containing 50×10^3 spores per milliliter. In vitro basidiospore germination was at least 88 percent.

The experimental design was a 12 x 4 x 2 x 4 factorial. Four flats of each family were inoculated on each of two consecutive days with each of the four spore sources. In four families where seed germination was low, only three flats were inoculated with each of the four spore sources on two consecutive days. A balanced design for analysis of variance was obtained by estimating the missing observations with a covariance analysis. In all, 7040 seedlings were inoculated in the study, with each flat constituting an experimental unit. After inoculation the seedlings were grown in a greenhouse for 9 months before the percentage of seedlings with actively growing galls was recorded. Means were separated according to Duncan's multiple range test (Hick 1964).

RESULTS

Seedlings of family 10-226 had significantly higher percentages of infection from Baldwin County than from Houston County rust isolates (fig. 1), which verified the field observations. Family-specific isolates from families 10-226 and 2903-l were significantly more virulent when re-inoculated onto seedlings of their respective families than were the general rust populations from the areas where each collection originated. Seedlings from Jones 14 were also highly susceptible to the family-specific isolate from 2903-1, but relatively resistant to the other three rust sources. Families 2790-9, 3365-8, 3302-21 and 2790-O all shared this pattern of infection (fig. 1). Family 2936-5 was moderately resistant to the Houston County and 2903-l isolates, but moderately susceptible to the Baldwin County and 10-226 isolates. Family 3750-7 was the only family showing resistance to all four sources of the rust. The slash pine check and families 2907-4 and 4410-5 were highly susceptible to all rust sources.

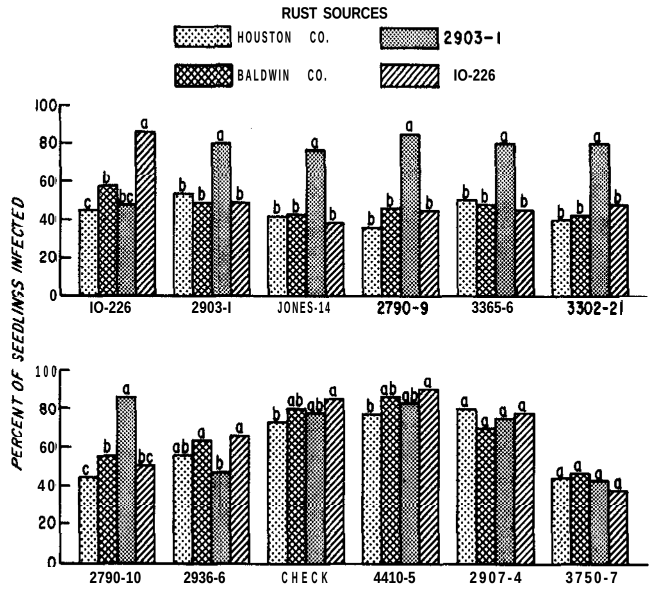

Figure 1.--Average percentages of infection produced by 4 rust sources on 12 slash pine families. Within families, means with the same letter do not differ significantly at the 0.05 level.

There were also highly significant differences between average percentages of infection produced by the four different sources of the rust. The family-specific collection from 2903-l caused an average of 72% infection, significantly more than any other isolate. The family-specific collection from family 10-226 produced 60% infection, while isolates from Baldwin and Houston counties caused 57% and 54%, respectively.

Interactions among host families and rust collections were highly significant. Infection ranged from 36% on family 2790-9 inoculated with the Houston County isolate to 91% on family 4410-5 inoculated with the family-specific isolate from 10-226. Some striking interactions were produced when the family-specific isolates were utilized to inoculate the seedlings of the families from which the spores were originally collected. For example, family-specific isolate 2903-l produced 80% infection when used to inoculate seedlings of that family, but it infected only 48% of the seedlings of family 10-226. Conversely, family-specific isolate 10-226 infected 86% of that family, while only infecting 49% of the seedlings from family 2903-L

DISCUSSION

Family 10-226 has been one of the most rust-resistant slash pine selections in southern tree improvement work. Its resistance has held up in many field test plantings in eastern Georgia, but at one location in central Georgia (Baldwin County) it appeared to be susceptible. The results from the artificial inoculations in our study confirm the field observations. The rust collected from Baldwin County was significantly more virulent on family 10-226 than that from Houston County, one of the highest disease hazard areas in Georgia according to the Fusiform Rust Incidence Survey (Phelps 1973). These results indicate the need for extreme caution in the selection and deployment of sources of resistance in large scale plantings, and particularly emphasizes the potential danger of single-family plantings and the need for information on the relative virulence of the pathogen in a specific area.

Family-specific collections from families 2903-l and 10-226 again confirm that aeciospores collected from susceptible members of a generally resistant progeny show an increase in virulence when they are used to reinoculate seedlings of the family from which they are collected. The percentage increase in infection was quite sizeable in both cases (48%). However, these results were from artificial inoculations which are probably more severe than natural infection in the field, and do not indicate that increases of this magnitude would occur in nature. They do indicate, as have other studies, that increased virulence of the rust population in a given area could be expected if specific sources of resistance were utilized for more than one generation (Powers et al. 1978, Snow et al. 1976). Therefore, in the deployment of resistant seedlings, it is very important to know the source of the resistance. For example, slash pine selection 2903-l was a seedling from the cross Jones 14 x Jones 11, with Jones 14 providing the resistance. Our inoculation results show that the family-specific rust isolate from 2903-l is highly virulent on both the selection from which it was derived, and its parental source of resistance. These results also demonstrate that family-specific rust collections can be useful in tracing sources of resistance back to parental material, and in detecting similarities in sources of resistance. They also indicate that family-specific rust collections do not necessarily increase in virulence on only one specific family, but may be more virulent on all families sharing a common type of resistance.

The possibility of using inoculation tests to identify different types of genetic resistance was suggested by Dinus et al. (1975). This type of approach was recently used by Griggs and Walkinshaw (1982) to demonstrate at least two types of resistance. At least four other families included in this study (2790-9, 2797-10, 3302-21 and 3365-8) seem to have the same type of resistance as 2903-l and Jones-14, since the infection patterns are almost identical (fig. 1). None of these families, however, were derived from Jones 14.

It i's very important to consider interactions between family and rust sources when evaluating the inoculation results from this study, since most families were either resistant or intermediate in resistance to most isolates while susceptible to at least one isolate. Only one of the families was resistant to all isolates (3750-7), and only one was susceptible to all isolates (4410-5). These results indicate at least three, and possibly four, types of resistance among these families: 1) Jones-14, 2) 10-226, 3) 3750-7, and 4) possibly 2936-5. The 3750-7 selection may contain a combination of the Jones 14 and the 10-226 type resistance rather than a different type.

Our results indicate that we need to know much more about the sources of resistance of various selections of slash pine available for tree improvement work in the Southeast. While many individual selections in orchards across the South provide resistance, several of these may derive their resistance from a common base. Those with common resistance should not be used in successive generations of reforestation in the same area because of the probability of an increase in virulence in the rust population of that area. Information on sources of resistance is therefore essential in making decisions regarding deployment of resistant pines.

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PERFORMANCE AND G-E INTERACTIONS OF SYCAMORE ESTABLISHED FROM CUTTINGS AND SEEDLING&

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Abstract.--Both unrooted cuttings and bare-root 1-O seedlings from eight open-pollinated sycamore families were planted together at one site in Mississippi. After seven years seedlings provided 16% better survival, 59% greater stem volume per acre, and 5% fewer multiple-stem trees than cuttings. Performance of both seedlings and cuttings increased as diameter of the propagule increased, indicating that only seedlings greater than 5/16-inch root collar diameter or cuttings greater than ½-inch basal diameter should be used in field plantings. Family differences at age seven for the combined performance of seedlings and cuttings were significant for survival, percent multiple-stem trees, height, and stem volume per acre. However, family ranks differed greatly between types of planting stack and resulted in significant G-E interactions. These interactions should be considered in sycamore tree improvement programs.

INTRODUCTION

Artificial regeneration with vegetative propagules of genetically superior clones can result in greater genetic gains than regeneration with open-pollinated seedlings from the same clones. However, poor survival and growth of unrooted cuttings and the high cost per propagule for rooted cuttings have offset this genetic-gain advantage for most forest tree species. In the southeastern United States only eastern cottonwood (Populus deltoides Bartr.) is being successfully established in commercial plantations with unrooted cuttings.

American sycamore (Platanus occidentalis L.) can be established with unrooted cuttings (Farmer 1974, McAlpine et al. 1972, Steinbeck and McAlpine 1973), but conflicting reports have arisen concerning the field performance of cuttings as compared with seedlings. Garrett (1975) reported no difference in growth between seedlings and cuttings, while others (Briscoe 1973, McAlpine 1965, Saucier 1977) have observed poorer survival and slower growth of cuttings than seedlings. [illegible] of these studies used cuttings from a cutting production nursery, as is done for cottonwood, but rather utilized cuttings taken directly from seedlings. The purposes of the present study are (i) to quantify the long-term effects on field performance of using seedlings versus unrooted cuttings from a cutting production nursery for plantation establishment, (ii) to determine the effect of seedling or cutting diameter on that performance, (iii) to learn if the size and part of the original seedling ortet used for cuttings to plant the cutting production nursery will have any effect on field performance of cuttings harvested from the nursery, and (iv) to determine if genotype-by-environmental (G-E) interactions exist with type of planting stock. The presence of such interactions would be an important consideration in any sycamore genetic improvement program where artificial regeneration with unrooted cuttings might be used.

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MATERIALS AND METHODS

Open-pollinated seed from eight trees scattered throughout the Gulf South were used (Table 1). Cuttings for establishment of a cutting production nursery were obtained as follows. First, seedlings were grown for one year in a nursery in 1973, lifted in the winter of 1973-74, and graded into three size classes: (i) "small" was less than 5/16-inch root collar diameter, (ii) "medium" was 5/16 to ½-inch diameter, and (iii) "large" was greater than ½-inch diameter. Each seedling was then cut off at the root collar, and the above-ground portion was divided into halves to give a basal cutting and a top cutting . These cuttings were planted as six treatments per family (three seedling sizes times two parts per seedling) in the cutting production nursery during March, 1974. Actual cuttings for the field study were taken one year later from the above-stump portions, or "wands", of the resulting rootstock plants in that nursery. The wands were cut in February, 1975, and the basal and terminal 12 inches on each wand were used. During 1974 a new crop of 1-O seedlings was raised in the nursery, lifted, and graded into the three size classes already described. These seedlings were used for the same field planting as the cuttings.

Table I.--Mother-tree locations of eight open-pollinated families used in the study.

Family I.D.	State	County or Parish	Latitude	Long.
A-l-2	Alabama	Marengo	32°16'N	87°55'W
B-2-l	Louisiana	Washington	30°45'N	89°50'W
G-2-7	Mississippi	Bolivar	33°34'N	91°09'W
H-l-l	Arkansas	Phillips	34°36'N	90°36'W
N-2-l	Mississippi	Jefferson	31°47'N	91°15'W
O-2-2	Louisiana	Catahoula	31°49'N	91°52'W
S-2-4	Arkansas	Grant	34°14'N	92°33'W
T-l-4	Mississippi	Marshall	34°35'N	89°28'W

The field study was planted in a split-plot design with the whole units (families) arranged in randomized complete blocks. There were four blocks, or replications. Subunits consisted of 15 types of planting stock, with each type represented by a single-tree plot within the family whole-unit plot. The 15 planting-stock types included three seedlings (small, medium, and large) and 12 unrooted cuttings (six treatments from the cutting production nursery times two parts of the wand). All propagules were planted at a ten-foot by ten-foot spacing in April, 1975, on an old-field site having a Stough fine sandy loam in Oktibbeha County, Mississippi (33°18' North latitude, 88°45' West longitude).

The diameter at the large end of each cutting and the root collar diameter of each seedling were measured before planting. Survival, number of stems per tree, and height were measured one, three, five, and seven years after planting. Diameter at breast height (DBH) was taken at years three, five, and seven. The stem volume per tree was calculated from the following equation[3/]:

$$\text{Stem volume} = -5.0525 + 0.86139 \times \ln(\text{DBH}^2 \times \text{Ht.})$$

where: stem volume is in cubic feet,
DBH is in inches, and
Ht. is in feet.

Stem volume yield per acre was then determined from the volume per tree, number of trees per acre at ten-foot by ten-foot spacing, and percent survival.

Effects of the 15 types of planting stock on seventh-year survival, percent multiple stems, DBH, height, and stem volumes were tested by orthogonal comparisons in an analysis of variance on plot means, where plots represented eight trees (one from each family). Percent survival and percent multiple-stem living trees were transformed by the arcsin-square-root transformation before analysis. Family and GE interaction effects were tested on plot means for five planting-stock types: (I) seedlings and (ii-v) four types of cuttings (two positions on the wand times two positions on the original seedling used for the nursery rootstock).

RESULTS AND DISCUSSION

Effects of Type and Size of Planting Stock

Unrooted Cuttings

Cuttings taken from the basal 12 inches of the wand produced seven-year-old trees having significantly greater survival, DBH, height, stem volume per tree, and stem volume per acre than cuttings obtained from the top 12 inches of the wand (Table 2). Only the percentage of living trees having multiple stems was unaffected by cutting position within the wand. Basal wand cuttings produced 83 percent more yield in stem volume per acre at age seven than did top cuttings.

[3/] Equation developed by the author from destructive sampling at the planting site for a Department of Energy subcontract with Oak Ridge National Laboratory.

Seventh-year survival, growth, and yield from all types of cuttings were directly related to the diameter of the cutting at the time of planting, with larger diameters giving higher performance (Figure 1). Cuttings from the base of the wand were significantly larger in diameter than those from the top, and when adjusted for differences in size (Table 2) the significant differences for many of the seven-year traits were removed. If unrooted cuttings are to be used for establishment of sycamore plantations, basal diameters of the cuttings should be one-half to three-quarters inch in size.

The nature of the original cuttings used to establish the rootstock in the cutting-production nursery had little effect on the field performance of wand cuttings (Tables 3 and 4). However, there was some evidence that the average diameter of the wand cuttings would be less for rootstocks derived from the tops of seedlings and from small seedlings than for rootstocks coming from the base of the seedling's stem or from large seedlings. Therefore, basal cuttings from seedlings with greater than 5/16-inch root collar diameter should be used to establish nursery rootstocks, in order that subsequent cutting production can be maximized.

Seedlings

Differences between small seedlings (less than 5/16-inch root-collar diameter), medium seedlings (5/16 to ½ inch), and large seedlings (greater than ½-inch diameter) were not significant at the 0.05 significance level for seventh-year traits (Table 5). However, the difference between small seedlings and the two large sizes fell close to significance for DBH, stem volume per tree, and stem volume yield per acre. Large seedlings produced 30-percent more stem volume per acre than the small seedlings.

Significant positive relationships were obtained when seventh-year DBH and stem volume per acre were regressed on seedling root-collar diameter (Figure 1). Similar regressions for stem volume per tree and for survival were close to being significant (probability level between 0.05 and 0.08). Therefore, only seedlings with root collar diameters greater than 5/16 inch should be used for seedling planting programs. This conclusion agrees with earlier recommendations of Nugent (1971).

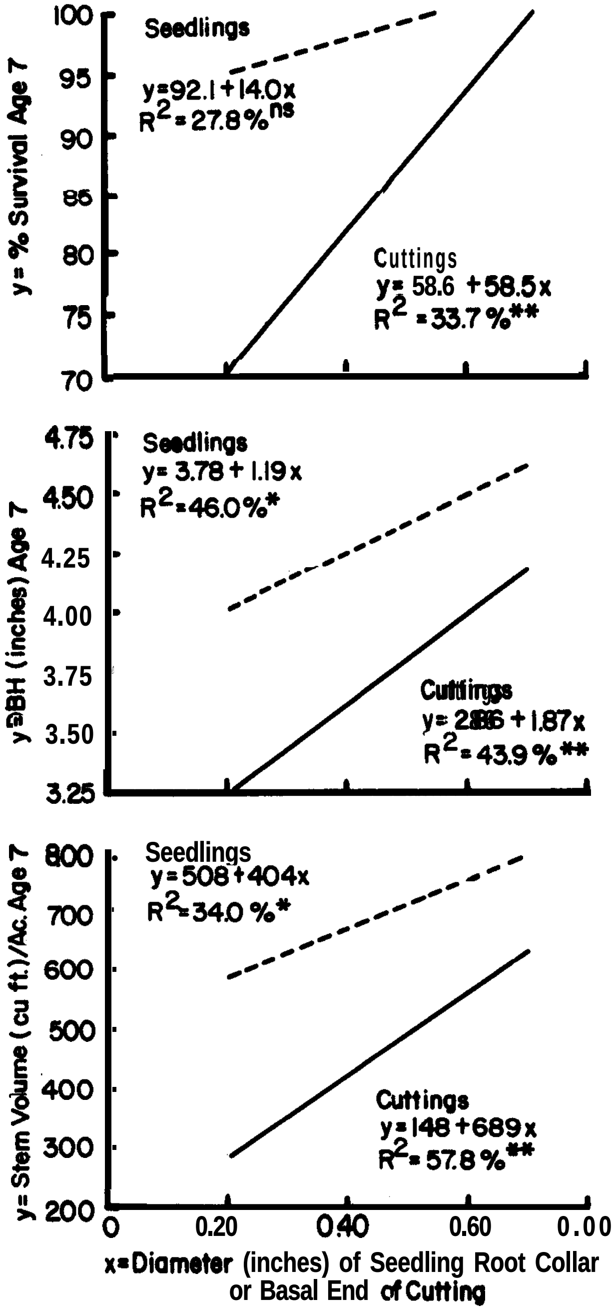


Figure 1.--Linear regression relationships between the diameter of the seedling or unrooted cutting and seventh-year survival, DBH, and stem volume per acre.

Table 2.--Means and significance of differences for performance of cuttings from the base and top of a wand.

Type of Propagule Planted	At Planting Time Diameter (inches)	7 Years After Planting Survival (%)	Mult.-Stem Trees (%)	DBH (inches)	Height (feet)	Stem Vol. (cu.ft.) Per Tree	Stem Vol. (cu.ft.) Per Acre
Cuttings from:							
Base of Wand	0.58	94	9	3.9	30.8	1.35	553
Top of Wand	0.24	71	5	3.3	28.8	0.98	303
F-test significance levels[1] for wand basal cuttings vs. wand top cuttings:							
(1) Unadjusted	(.000)**	(.014)*	(.102)	(.015)*	(.033)*	(.016)*	(.012)*
(2) Adjusted[2]	--	(.433)	(.507)	(.033)*	(.095)	(.012)*	(.142)

Table 3.--Means and significance of differences for performance of cuttings from rootstocks originally derived from three size classes of seedlings.

Type of Propagule Planted	At Planting Time Diameter (inches)	7 Years After Planting Survival (%)	Mult.-Stem Trees (%)	DBH (inches)	Height (feet)	Stem Vol. (cu.ft.) Per Tree	Stem Vol. (cu.ft.) Per Acre
Original cuttings for nursery rootstock from:							
Small Seedlings	0.38	84	5	3.5	29.7	1.14	424
Medium Seedlings	0.40	82	11	3.6	29.3	1.10	410
Large Seedlings	0.44	81	5	3.8	30.4	1.25	449
F-test significance levels[1] for cuttings from small seedlings vs. cuttings from (medium+large) seedlings:							
(1) Unadjusted	(.105)	(.496)	(.309)	(.364)	(.834)	(.693)	(.843)
(2) Adjusted[2]	--	(.839)	(.334)	(.996)	(.825)	(.770)	(.840)
F-test significance levels for cuttings from medium seedlings vs. cuttings from large seedlings:							
(1) Unadjusted	(.081)	(.339)	(.066)	(.566)	(.360)	(.458)	(.613)
(2) Adjusted[2]	--	(.559)	(.200)	(.861)	(.586)	(.839)	(.883)

1/Actual probability level for F-test is shown in parentheses. Significance at the 0.05 probability level is designated by '*', and significance at the 0.01 level is indicated by '**'.

2/Adjusted by covariance analysis for the diameter at time of planting.

Table 4.--Means and significance of differences in performance of cuttings from rootstocks originally derived from the base of seedlings versus those from the top of seedlings.

Type of Propagule Planted	At Planting Time Diameter (inches)	7 Years After Planting Survival (%)	Mult.-Stem Trees (%)	DBH (inches)	Height (feet)	Stem Vol. (cu.ft.) Per Tree	Per Acre
Original cuttings for nursery rootstock from:							
Base of seedling	0.43	82	6	3.7	29.8	1.18	429
Top of seedling	0.39	82	8	3.6	29.8	1.15	426
F-test significance levels[1] for seedling basal cuttings vs. seedling top cuttings:							
(1) unadjusted	(.028)*	(.959)	(.754)	(.434)	(.920)	(.484)	(.888)
(2) Adjusted[2]	--	(.970)	(.866)	(.530)	(.247)	(.731)	(.718)

Table 5.--Means and significance of differences for performance of seedlings from three size classes.

Type of Propagule Planted	At Planting Time Diameter (inches)	7 Years After Planting Survival (%)	Mult.-Stem Trees (%)	DBH (inches)	Height (feet)	Stem Vol. (cu.ft.) Per Tree	Per Acre
Small Seedlings	0.22	94	3	4.0	30.5	1.41	581
Medium Seedlings	0.42	100	3	4.4	31.6	1.62	703
Large Seedlings	0.64	100	0	4.5	32.3	1.73	753
F-test significance levels[1] for small seedlings vs. (medium + large seedlings):							
(1) unadjusted	(.000)**	(.182)	(.718)	(.064)	(.090)	(.075)	(.069)
(2) Adjusted[2]	--	(.896)	(.455)	(.568)	(.494)	(.618)	(.656)
F-test significance levels for medium seedlings vs. large seedlings:							
(1) Unadjusted	(.000)**	(1.000)	(.391)	(.103)	(.298)	(.291)	(.291)
(2) Adjusted[2]	--	(1.000)	(.555)	(.308)	(.243)	(.371)	(.371)

[1] Actual probability level for F-test is shown in parentheses. Significance at the 0.05 probability level is designated by '*', and signficance at the 0.01 level is indicated by '**'.

[2] Adjusted by covariance analysis for the diameter at time of planting.

Seedlings versus Unrooted Cuttings

Seven-year-old trees established from seedlings (three sizes combined) had a significantly lower percentage of multiple stems and greater survival, DBH, height, stem volume per tree, and stem volume per acre than trees planted as unrooted cuttings (12 cutting treatments combined) (Table 6). These differences can be attributed, in part, to the poor performance of the top cuttings (Figures 2 and 3). Some of the superiority of seedlings over unrooted cuttings can be removed by using only large diameter cuttings, but for equivalent root-collar diameters the seedlings are always better than the cuttings (Figure 1).

Almost all of the mortality occurred in the first year (Figure 2). Weed competition probably contributed to the lower survival of cuttings than of seedlings. The initial height advantage of the seedlings over the cuttings helped to keep leaves above the weeds during intervals between cultivations. This height advantage also allowed the seedlings to be more easily seen by tractor operators, thereby reducing the risk of mechanical damage during cultivation.

Multiple-stem trees usually contained two stems. The percent multiple-stem trees decreased with age for both seedlings and cuttings, as one stem gained dominance. However, trees still having multiple stems by age seven will probably remain that way throughout longer rotations. The greater percentage of multiple-stem trees from cuttings than from seedlings may result in poorer stem quality and greater harvesting problems at the end of the rotation.

Stem volume yields per acre at age seven were 59 percent greater (679 versus 428 cu. ft. per acre) for a plantation established with seedlings (three sizes combined) at a lo-foot by IO-foot spacing than for a similar plantation established with unrooted cuttings (12 types combined). When only basal cuttings from the wands were used in the comparison, the yield differential between seedling and cutting propagation methods was 23 percent (679 versus 553 cu. ft. per acre). Such differences in yield indicate that use of unrooted cuttings in sycamore planting programs will only be justified for genetically improved stock, where the genetic gain would be at least 23 percent better than what would be obtained with improved seedlings. These additional gains would have to come from use of (i) non-additive genetic variation, for which we presently have no information, and/or (ii) GE interactions with type of planting stock.

Family Effects and GE Interactions

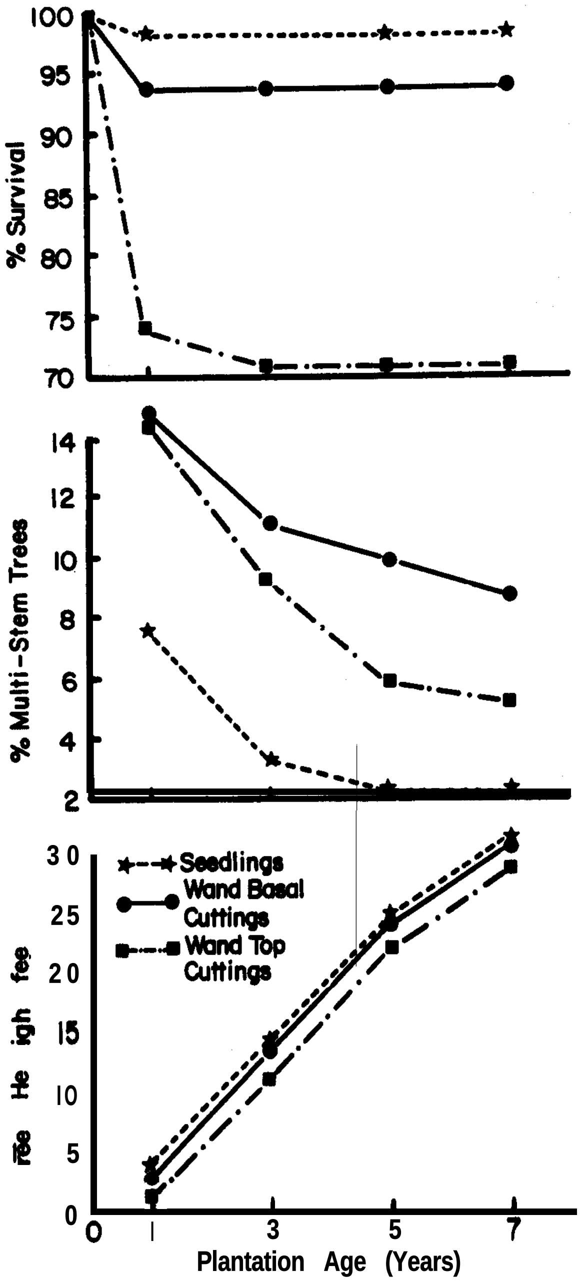
The mother-tree families differed significantly for seventh-year survival, percent multiple-stem trees, height, and stem volume yield per acre, but not for DBH or stem volume per tree (Table 7). However, the significant yield differences among families cannot be attributed wholly to survival differences . Family means in Table 7 indicate that DBH and stem volume per tree, even though not significantly different among families, contributed to the family differences in yield. Significance of these yield differences was primarily due to families S-2-4 and O-2-2, which had both poorer than average survival and low stem volume per tree. The best family for yield per acre, H-l-l, produced 12 percent more volume than the average for all eight families.

Table 6.--Means and significance of differences in performance for seedlings versus unrooted cuttings.

Type of Propagule Planted	At Planting Time: Diameter (inches)	7 Years After Planting: Survival (%)	Mult.-Stem Trees (%)	DBH (inches)	Height (feet)	Stem Vol. (cu.ft.) Per Tree	Stem Vol. (cu.ft.) Per Acre
Seedlings	0.42	98	2	4.3	31.4	1.59	679
Cuttings	0.41	82	7	3.6	29.8	1.17	428
F-test significance level[1] for seedlings vs cuttings:							
(1) Unadjusted	(.206)	(.003)**	(.024)*	(.004)**	(.024)*	(.011)**	(.008)**
(2) Adjusted[2]	--	(.038)*	(.033)*	(.032)*	(.113)	(.052)*	(.048)*

[1] Actual probability level for F-test is shown in parentheses. Significance at the 0.05 probability level is designated by '*', and signficance at the 0.01 level is indicated by '**'.

[2] /Adjusted by covariance analysis for the diameter at time of planting.



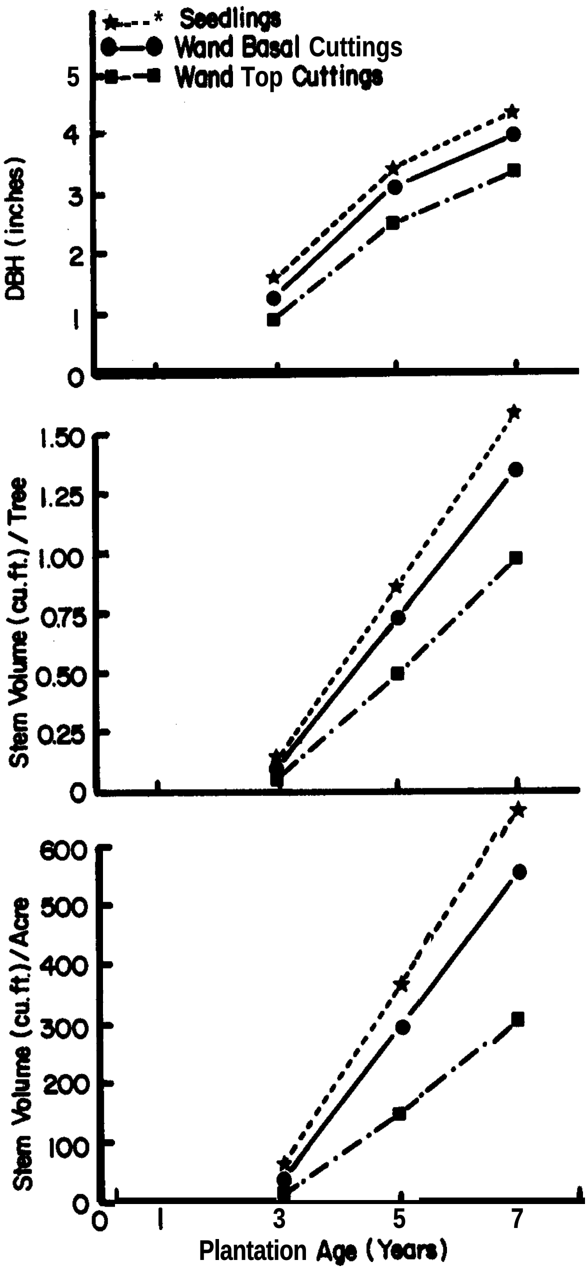


Figure 2.--Survival, percent multiple-stem trees, and mean height of trees during the first seven years following establishment with either seedlings or cuttings.

Figure 3.--DBH and stem volume of trees during the first seven years following establishment with either seedlings or cuttings.

Table 7.--Family means and significance of family variation for seventh-year field performance of seedlings and cuttings combined.

Family,	Survival (%)	Multiple Stems (% of live trees)	DBH (in.)	Height (ft.)	Stem Volume (cu.ft.) Per Tree	Stem Volume (cu.ft.) Per Acre
A-l-2	90	12	3.8	31.3	1.28	503
B-2-l	91	4	3.7	30.9	1.25	505
G-2-7	92	11	3.8	30.7	1.26	501
H-l-l	85	2	4.0	30.4	1.39	540
N-2-1	87	2	3.9	30.4	1.29	503
0-2-2	85	3	3.6	28.5	1.17	451
S-2-4	73	3	3.4	27.1	1.01	344
T-l-4	83	10	3.9	30.8	1.34	502
Mean	86	6	3.8	30.0	1.25	481
F-test significance levels[1/] for family variation:						
	(.049)*	(.038)*	(.305)	(.043)*	(.214)	(.021)*

Measurements after 7 Growing Seasons

[1/] Tests conducted on arcsin of the square root of percent survival or percent multiple stems. Actual probability level for F-test is shown in parentheses. Significance at the 0.05 probability level is designated by '*'.

The lack of significant family differences for DBH and stem volume per tree was a result of large G-E interactions with seedlings versus cuttings, where high family values for one type of planting stock were offset by low values for the other type (Table 8). Significance levels for the interaction were 0.036 for stem volume per tree and 0.072 for DBH.

Family G-E interactions with cuttings taken from the base of the wand versus cuttings taken from the top were observed for survival (Table 9) and stem volume per acre (Table 10). Family A-l-2 was the primary contributor to this interaction, since it was the only family whose top cuttings had better survival than the basal cuttings.

Even though unrooted cuttings usually did not perform as well as seedlings, there were some families where wand basal cuttings were equal to seedlings in performance. Family B-2-l produced just as much stem volume per tree and per acre from basal cuttings as from seedlings (Tables 8 and 10). Survival of basal cuttings for family S-2-4 was superior to survival of the seedlings from that family (Table 9).

These examples of G-E interactions provide hope that unrooted cuttings will be a viable alternative to bare-root seedlings in planting programs of some sycamore genotypes, The causes of the interactions are beyond the scope of the present study, but may be related to genetic differences in internal composition, amounts, and distribution of photosynthates and nutrients at the time of seedling lifting or cutting harvest. Lee and Oh (1978) have reported that rooting and growth of transplanted sycamore trees is best when the soluble sugar content is high and moisture content is low.

Table 8 .--Family means and significance of GE interactions for stem volume per tree.

Family	Type of Propagule Planted			
			Cuttings taken from:	
	Seedlings (A)	Cuttings (B)	Wand Base (C)	Wand Top (D)
	------Stem Volume	(cu.ft./tree)	and (Family	Rank)-----
A-l-2	1.54	1.22	1.34	1.10 (2)
B-2-l	1.39 (8)	1.22	1.47	0.96
G-2-7	1.44 (7)	1.22	1.29	1.14 (1)
H-l-l	1.78 (2)	1.29 (1)	1.56 (1)	1.03
N-2-l	1.59	1.22	1.39	1.05
O-2-2	1.88 (1)	0.99 (7)	1.23 (7)	0.75 (7)
S-2-4	1.55	0.88 (8)	1.08 (8)	0.68 (8)
T-l-4	1.57	1.28 (2)	1.53 (2)	1.03
F-Tee t Significance	Family x (A vs B) = * (.036 prob. level)		Family x (C vs D) = ns (.447 prob. level)	

Table 9 .--Family means and significance of GE interactions for percent survival.

Family	Type of Propagule Planted			
			Cuttings taken from:	
	Seedlings (A)	Cuttings (B)	Wand Base (C)	Wand Top (D)
	---------Percent	Survival and	(Family Rank)	-----------
A-l-2	100	88	79 (8)	96 (1)
B-2-l	100	89	96	81 (2)
G-2-7	100	90 (1)	100 (1)	79
H-l-l	100	81	92 (7)	71
N-2-l	100	83	96	71
O-2-2	100	81	96	67
S-2-4	84 (8)	71 (8)	96	46 (8)
T-l-4	100	79	96	63 (7)
F-Test[1/] Significance	Family x (A vs B) = ns (.997 prob. level)		Family x (C vs D) = ** (.003 prob. level)	

1/ Tests conducted on arcsin of the square root of percent survival.

Table 10.--Family means and significance of GE interactions for stem volume per acre.

	Type of Propagule Planted			
			Cuttings taken from:	
Family	Seedlings (A)	Cuttings (B)	Wand Base (C)	Wand Top (D)
	------Stem Volume (cu.ft./ac.) and (Family Rank)-------			
A-l-2	671	461	456 (7&8)	466 (1)
B-2-l	605 (7)	480 (2)	613	348
G-2-7	629	469	560	378 (2)
H-l-l	775 (2)	482 (1)	619 (2)	344
N-2-l	694	455	583	327
O-2-2	818 (1)	359 (7)	516	202 (7)
S-2-4	557 (8)	291 (8)	456 (788)	125 (8)
T-l-4	685	456	640 (1)	273
F-Test Significance	Family x (A vs B) = ns (. 142 prob. level)		Family x (C vs D) = * (.012 prob. level)	

CONCLUSIONS

The type of planting stock used to establish a sycamore plantation will affect survival, frequency of multiple stems, growth, and stem volume yield for at least seven years following establishment. Bare-root seedlings will outperform unrooted cuttings. Diameter of seedling or cutting is important, with large seedlings outgrowing small seedlings and large-diameter cuttings from the base of the wand outperforming small cuttings from the top. The size and part (base versus top) of seedling ortets used to establish rootstock in a cutting-production nursery can affect amounts of cuttings eventually harvested, but will have no carry-over ef fect on field performance of those cuttings.

Family differences and GE interactions with types of planting stock do exist. In some cases the top ranking families for one type of planting stock are the poorest for another type stock. Even though seedlings usually outperformed unrooted cuttings in the present study, there were families whose large diameter basal cuttings performed just as well as the seedlings. Genotypes with this character must be identified in existing sycamore tree imprwement programs, if unrooted cuttings are to provide a viable alternative to seedlings for establishment of sycamore plantations. Such an alternative would be desirable, since it would allow the utilization of nom-additive genetic variation for increased genetic gains.

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POLLEN STORAGE METHODS INFLUENCE FILLED SEED YIELDS

IN CONTROLLED POLLINATIONS OF LOBLOLLY PINE[1/]

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Abstract.--Four clones of loblolly pine were control-pollinated with fresh pollen and with 3-year-old vacuum-stored and desiccator-stored pollen. Storage treatments did not significantly affect the total number of developed seeds produced per cone. The number of filled seeds per cone and the percent filled seeds per cone were higher after vacuum than after desiccator storage. Rehydration of pollen did not significantly affect total, filled, or percent filled seed yields from controlled pollinations. Vacuum drying of loblolly pine pollen is recommended for long-term storage.

INTRODUCTION

Controlled pollination is an integral part of tree improvement programs; it is used to test progeny of parental selections and to provide future selections for advanced generation breeding. This paper reports total seed and filled seed'yields obtained from loblolly pine (Pinus taeda L.) cones produced from controlled pollinations with pollen stored by two methods currently in use at the Southeastern Forest Experiment Station. Most tree breeders are producing enough seeds for their needs, but it is important to pollinate as efficiently and effectively as possible because the operation requires expensive hydraulic lifts and considerable labor. There appears to be considerable room for improvement in the number of seeds produced. For example,the potential number of seeds per loblolly pine cone is about 155 (Bramlett 1974). However, filled seed yields per cone are averaging only '30-35 in many breeding programs.61 If high yields of filled seeds, e.g., 100 per cone, could be produced consistently, breeding costs would be reduced.

Seed yields from controlled pollination can be influenced by the vigor and viability of pollen, which often must be stored for several years before use. In general, fresh pollen is preferred to stored pollen, but individual pines release pollen at the same time or later than female strobilus receptivity. Thus, unless anthesis of the desired male parent is fortuitously earlier than the selected female parent or the male parent is growing in a more southerly latitude where it would flower earlier (Dorman and Barber 1956), it is usually difficult to use fresh pollen to complete a large number of controlled pollinations. Thus, tree breeders have considerable interest in pollen storage methods. The collection, processing, and storage of pollen has recently been discussed by Sprague and Snyder (1981) and Matthews and Kraus (1981).

METHODS AND MATERIALS

Pollen Collections and Storage

Dehiscing catkins were collected from three clones (538, 573, 579) at the Georgia Forestry Commission's Arrowhead Seed Orchard in Pulaski County, Georgia, in March 1977. The catkins were dried at 32°C and the pollen was extracted and sieved through a 100 mesh screen. The freshly

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extracted pollen was placed by clone in 4-ounce glass bottles and then loosely capped and temporarily stored over calcium chloride in a desiccator at 2°C. After 4 weeks, the pollen was divided into two storage treatments: (1) Five cc of pollen were placed in each of several ampules and vacuum-dried until moisture content was 2-3 percent (2 hours at 0.05 mm Hg). The ampules were then heat-sealed and stored at 2°C. for 3 years: (2) The remainder of the pollen was left in the desiccator at 2°C in the loosely capped 4-ounce glass bottles with each bottle approximately 40 percent filled, Moisture content after 3 years was 6-9 percent. Fresh pollen was collected from the same three clones in 1980.

Controlled Pollinations

Four Georgia Forestry Commission clones in the Arrowhead Seed Orchard (539, 584, 608, and 632) were selected for female parents. On a single ramet of each clone, 30 branches bearing female strobili were tagged, and one of six controlled pollination treatments was randomly assigned to four branches for each treatment. The branches were enclosed in sausage casing isolation bags on March 18-19, 1980. For a control, six randomly selected branches per tree were not bagged and thus were wind pollinated. For each storage method, pollen was either rehvdrated or not rehvdrated. Stored pollen has a greater in vitro germination if rehyhrated at 100 percent relative humiditv for 16 hours before testing (Goddard and Matthews 1981). Treatments were :

TREATMENT NO.	STORAGE METHOD	REHYDRATION
1	Vacuum	Yes
2	Vacuum	No
3	Desiccator	Yes
4	Desiccator	No
5	Fresh	Yes
6	Fresh	No
7	Wind	--

Just prior to pollination, a polymix of each of the three pollen types was made by mixing equal volumes of pollen from each of the three clones. Agar plate testing of rehydrated pollens (Goddard and Matthews 1981) at the time of pollination showed <u>in vitro</u> germination of fresh pollen to be 98 percent, vacuum-stored pollen 94 percent, and desiccator-stored pollen 91 percent.

A cyclone pollinator (Matthews and Bramlett 1981) was used in a single application of 0.50 cc of pollen per bag. Pollinations were made on March 29 and 31, 1980, when the majority of the bagged strobili were at maximum receptivity. Isolation bags were removed 2 weeks after pollination.

Cone Collections and Analysis

All healthy cones were collected in early October 1981 and 10 cones were randomly selected per treatment for detailed measurements and cone analysis. In the cone analysis (Bramlett, et al. 1977), all fertile scales were removed and the total number of seeds recorded for each cone. Radiographs were used to determine the number of filled seeds per cone. A total of 274 cones were analyzed. Treatment and clonal mean values were compared by analysis of variance.

RESULTS AND DISCUSSION

Total Seeds Per Cone

The total number of seeds per cone is a measure of seed setting ability of the cone and indicates the number of ovules pollinated with at least one viable pollen grain. If ovules are unpollinated or if the pollen fails to germinate on the nucellus tissue, the ovule aborts during the first year of development and does not form a seedcoat (Bramlett et al. 1977).

Storage method did not significantly affect the total yield of seeds per cone when the six treatment means were compared (Table 1). Also, the rehydration did not significantly increase the total seed yield within each storage method. Thus, although the rehydration is necessary for in vitro germination tests, it does not appear to be important for controlled pollinations.

Filled Seeds Per Cone

As the total number of seeds per cone is a measure of the number of ovules pollinated with viable pollen grains, the number of filled seeds per cone is a measure of the number of seeds containing an embryo and gametophyte tissue (occasionally seeds may have gametophyte tissue without an embryo). Since only filled seeds are capable of germinating to produce seedlings, this is the most important measure of successful pollination procedures. If fertilization fails to occur, or if the embryo aborts soon after fertilization, then the gametophyte tissue does not develop. The seedcoat, however, is full size at the time of fertilization and abortion of the embryo and gametophyte leaves an empty seed or "pop". In this study, filled seed yields were significantly reduced when desiccator-stored pollen was used (Table 2). Both the vacuum-stored and fresh pollen produced very high filled seed yields per cone. The desiccator-stored pollen, however, only produced about one half the number of filled seeds per cone, averaging 45 to 52 seeds per cone compared to 97 to 99 filled seeds per cone with vacuum-stored pollen and 100 to 103 filled seeds per cone with fresh pollen.

Table 1.--Total seed yields per cone from loblolly pine cones control-pollinated with rehydrated and nonrehydrated vacuum-stored, desiccator-stored, or fresh pollen

GFC CLONE NO.	POLLEN STORAGE METHOD: VACUUM REHYD.	VACUUM NONREHYD.	DESICCATOR REHYD.	DESICCATOR NONREHYD.	FRESH REHYD.	FRESH NONREHYD.	WIND
	Total Seed/Cone						
539	114	117	109	104	98	109	121
584	120	122	109	114	135	116	124
632	131	99	141	92	120	132	155
608	117	113	124	99	114	122	128
MEAN[1/]	121 a	113 a	120 a	103 a	117 a	120 a	132

[1/] Means not designated with the same letter are significantly different at the 0.05 level of probability by Duncan's New Multiple Range Test. Wind-pollinated cones were not included in the analysis.

Table 2.--Number and percent filled seeds per cone from loblolly pine cones control pollinated with rehydrated and nonrehydrated vacuum-stored, desiccator-stored, or fresh pollen

GFC CLONE NO.	POLLEN STORAGE METHOD												WIND	
	VACUUM				DESICCATOR				FRESH					
	REHYD.		NONREHYD.		REHYD.		NONREHYD.		REHYD.		NONREHYD.			
	Filled Seed/Cone													
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
539	109	95	112	95	55	50	55	53	92	93	102	93	114	94
584	103	84	110	90	45	38	46	40	122	90	104	89	110	88
632	83	64	78	79	56	40	27	30	90	75	99	75	106	69
608	101	86	85	75	51	41	45	45	98	86	108	88	105	81
Mean[1/]	99a	82a	97a	85a	52b	43b	45b	43b	100a	86a	103a	86a	109	83

[1/] Means not designated with the same letter are significantly different at the 0.05 level of probability by Duncan's New Multiple Range Test. Wind-pollinated cones were not included in the analysis.

Percent Filled Seed

The actual number of filled seeds per cone is of the greatest importance to tree breeders, but the ratio of filled seed to total seed or the percentage of filled seeds is frequently used to evaluate overall seed production performance. The percentage of filled seeds rarely approaches 100 percent, even with wind-pollinated cones, because many factors including insect damage, genetic embryo incompatibility, fungi, and physiological stress may cause embryo abortion and empty seeds.

In this study, the pollen storage method significantly affected the percentage of filled seeds (Table 2). The value for 3-year-old desiccator-stored pollen averaged only 43 percent compared to 82-85 percent for vacuum-stored pollen, 86 percent for fresh pollen, and 83 percent for wind pollen. Pollen that was vacuum-stored, desiccator-stored, or freshly collected all had over 90 percent germination *in vitro* before pollination. Also, the high total seed yields support the view that the pollen was also viable *in vivo* as no difference was observed in total seed yields per cone. From these observations, we conclude that viable pollen was present in the strobili pollinated with desiccator-stored pollen; yet, healthy embryos were produced in only 43 percent of the ovules.

Two possible explanations for the low percentage of filled seeds depend on the probability that the desiccator-stored pollen was viable but had only marginal vigor. Germination of this pollen in the ovule stimulated ovule and seedcoat development but the pollen may not have continued growth the second year to complete fertilization. Without fertilization the embryo and gametophyte would abort. Alternatively, fertilization may have occurred with the desiccator-stored pollen, but the embryo may have been too weak to continue development and may have aborted soon after fertilization. Either event would lead to an empty seed.

CONCLUSIONS

This study demonstrates that vacuum storage of loblolly pine pollen is highly effective for at least 3 years. Both the total and filled seed yields per cone following controlled pollinations with vacuum-stored pollen were comparable to the seed yields from pollinations with freshly collected pollen. With desiccator-stored pollen, the total seed yield was equal to those with vacuum or fresh pollen sources, but the filled seed yield per cone was considerably reduced. The relatively high moisture content of the desiccator-stored pollen could decrease viability by allowing continued pollen metabolism and by promoting detrimental activities of **fungal** and bacterial contaminants during the storage period. Vacuum drying and storage produce an atmosphere of low moisture and gaseous content, thus decreasing these destructive processes and reducing pollen deterioration (Matthews and Kraus 1981).

There are numerous advantages of a reliable and consistent long-term storage procedure for pine pollen. With properly stored pollen of high viability, only a few isolation bags are needed per cross. As was demonstrated in this study, when vacuum-stored pollen is used, only five or six pollination bags and about 20-25 female strobili should produce more than 1,000 filled seeds per cross. Furthermore, once pollen has been placed in vacuum storage at low moisture content it remains highly viable for at least 5 years so that additional collections are unnecessary.[5] Also, efficient and effective storage and pollination procedures reduce the quantity of pollen to be collected, processed, and stored. A single ampule containing 5 cc of vacuum-stored pollen is adequate for each cross. These procedures can substantially reduce breeding costs by reducing the number of isolation bags and strobili required per cross. In addition, more individual crosses can be completed in a given breeding season, and breeding may begin on younger trees when the number of female strobili is small, thereby accelerating the improvement of southern pines.

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SIMULATED GROWTH AND YIELD OF SINGLE-FAMILY VERSUS MULTI-FAMILY LOBLOLLY PINE PLANTATIONS[1/]

Warren L. Nance[2/]

Abatract .--A simulator (PTAEDA) waa modified to simulate the growth and yield of loblolly pine plantations established with single families and mixtures of families with different genetic growth potential. The simulations indicate that the yield of mixed plantations may be predictable using the yields of single family plantations combined in an additive model. However, the relative contribution of a family to the total volume in a mixed plantation is less predictable and depends on which families are mixed and in what proportions. Based on these results, mixed plantations probably would not yield more than a single family plantation of the best component family planted on the same site. However, mixed plantations may offer other advantages that could be utilized by forest managers.

INTRODUCTION

The primary goal of loblolly pine (*Pinus taeda* L.) tree improvement programs is the production of planting stock that is superior to woodsrun stock in growth, form, and resistance to diseases and insects. Forest geneticists have selected and tested many individual trees that exhibited phenotypic superiority in one or more of these traits. The most promising selections have been placed in production seed orchards which currently produce most of the seed used to plant industry and government land as well as a large percentage of that used for private land.

Fundamental questions arise when seed is collected in the orchard. Should seed from each family be collected and maintained separately, or should the seed be bulked without regard to family identity? Should the seed orchard manager, the forest geneticist or the forest manager make the decision? If the decision is to mix families, which ones should be mixed and in what proportion?

In practice, most seed orchard managers bulk the seed, producing a complex mixture in which all families are mixed in proportion to the number of seeds they produce. The only factor determining the proportion of each family in the mix is that family's relative seed production in that year. There are many valid arguments against this practice (Gladstone 1980). One of the strongest is that all future options regarding mixing are eliminated in the seed orchard by the mixing. If seed from each family were collected and kept separate in the orchard, then forest managers and geneticists could evaluate different mixing alternatives and choose the most desirable alternative. That strategy could then be executed by mixing (or not mixing) seed or seedlings from different families in planned proportions.

Some managers are collecting and maintaining seed separately for each family in the orchard, and it seems likely that more orchards will adopt this approach. Forest managers and geneticists, then, must be able to evaluate various mixing alternatives. However, not enough is known about the effects of mixing on the growth and yield of loblolly pine plantations to develop optimum mixing strategies. Mixing experiments using loblolly pine seedlings one or two years old have been reported (Adams et al. 1973, Snyder and Allen 1971), but results based on seedling growth cannot be extended with confidence to plantation growth and yield.

A review of the agricultural crop science literature reveals a vast amount of activity in

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regard to mixing different varieties of the same crop, and yet the results are not conclusive enough in most crops to allow crop scientists to choose between mixes or monotypes as a general strategy. There are, however, specific situations that favor mixing. For example, there is a tendency in some crops for mixes to produce more stable yields than monotypes when planted over a range of differing environments (Frey and Maldonado 1967, Allard 1961, Allard and Bradshaw 1964, Jensen 1965, Qualset and Granger 1970, and Simmonds 1962). Also, there is some evidence that the risk to disease loss may be less for mixes than for monotypes (Browning and Frey 1969). Whether or not mixing could provide similar benefits in loblolly pine is unknown.

Perhaps the only way to resolve the mixing controvery is to establish mixing experiments in forest trees similar to those common in crops. Such experiments are being initiated now, but even if they are installed in the field next year, it will take at least 5 to 10 years for meaningful results to accumulate. Even then, only a small number of the possible mixing combinations can be included in any field experiment of reasonable size.

In the interim, the decision to plant single or multi-family plantations could have far reaching economic and biological effects, and any insight into the mixing phenomenon provided by computer simulation could be valuable to forest scientists and others faced with such decisions. For example, computer simulations of the growth and yield of single family and multi-family plantations of loblolly pine could complement the experimental approach to the mixing problem by helping scientists evaluate the various field designs that have been used in crops for applicability to loblolly pine. This could be very helpful in view of the large investment of resources required for complex, long term experiments in forest trees. Simulations could also help managers evaluate the advantages and disadvantages of mixing during the next few years before experimental data become available.

In this paper, a modified loblolly pine individual-tree growth and yield model is presented that allows mixing of loblolly pine families with different growth potentials in various proportions. A classic crop mixing experiment, the DeWit (1960) replacement series, is simulated, and from the results some general insights into the mixing problem in even-age loblolly pine plantation management are developed.

METHODS

The loblolly pine individual tree growth and. yield simulator named PTAEDA (Daniels and Burkhart 1975) was chosen as a starting point in developing a mixing simulator. This simulator was originally developed for woodsrun plantations, and compares favorably with other growth and yield models in predicting the growth and yield of woodsrun loblolly pine plantations (Daniels et al. 1979). The original, unmodified FORTRAN version was named PTAEDA.

The Original Model.--PTAEDA is described fully in Daniels and Burkhart (1975), including a complete FORTRAN listing. Briefly, the simulator assigns coordinate locations in a stand and "grows" each tree annually. The growth of an individual tree is predicted as a function of the tree's current size, the site quality, and competition from neighbors. Predicted growth increments are then adjusted by adding a stochastic element representing individual-tree genetic and microsite variability. Individual tree mortality is also simulated by the program using the tree's competitive status and size to generate an expected probability of death which is then applied stochastically to the tree. Subroutines to simulate thinning, site preparation, and fertilization operate on the stand by removing trees from the stand, adjusting the response to competition from neighboring trees, or adjusting the site quality respectively.

The growth predictor in PTAEDA is based on certain assumptions regarding the way individual trees within a stand grow in the presence of competition. Basically, it is assumed that growth in height and diameter follows some theoretical growth potential that can only be attained by trees occupying dominant and codominant positions within the stand. An adjustment factor is applied to this expected main canopy growth increment based on a tree's competitive status and vigor -- intermediate and suppressed trees receive large reductions while dominant and codominant trees receive little or no adjustment from the theoretical maximum potential growth.

The expected main canopy annual height growth potential in the stand is given by the following formula:

$$\begin{aligned} PHIN(A1, A2) &= HD(A2) - HD(A1) \qquad (1)\\ &= [(SI)10^{-B(1/A1 - 1/25)}] \\ &\quad -[(SI)10^{-B(1/A2 - 1/25)}] \end{aligned}$$

where:

PHIN(A1, A2) = potential height increment from age A1 to age A2
HD(A1) = predicted mean height of the dominant and codominant trees in the stand at age A1
HD(A2) = predicted mean height of the dominant and codominant trees in the stand at age A2
SI = site index of the stand at index age 25.
B = Form coefficcent for the site index curve, equal to -5.86537. The site index curve is assumed to have the form:
$\log_{10}(HD) = a + B(1/A)$

This formula can be recognized as simply the first difference with respect to age of the site index curve for the stand. The predicted height growth of an individual tree in the period A1 to A2 is then given by:

$$HIN(A1, A2) = [B_1 + B_2(CR)^{B_3} e^{(B_4(CI)+B_5(LC)}] \times PHIN(A1, A2) \quad (2)$$

where:

- $HIN(A1, A2)$ = actual height increment of subject tree from age A1 to age A2.
- LC = live crown ratio of subject tree.
- CI = competition index of subject tree.
- $PHIN(A1, A2)$ = potential height increment from age A1 to age A2.
- e = 2.71814
- B_1 = 0.54631
- B_2 = 124.8635
- B_3 = 1.66254
- B_4 = -1.15083
- B_5 = -6.66226

The competition index (CI) used in the above equation, and elsewhere throughout the program, quantifies competitive stress for Individual trees and represents the total effect of competition for scarce resources. The index is a modified form of Hegyi's Index (Hegyl 1974) which has the following form:

$$CI_i = \sum_{j=1}^{n} (D_j/D_i)/DIST_{ij} \quad (3)$$

where:

- CI_i = competition index of the ith tree.
- D_i = d.b.h. of the subject tree.
- D_j = d.b.h. of the jth competing tree.
- $DIST_{ij}$ = distance between subject tree and and jth competitor.
- n = the number of neighbors falling within a Basal Area Factor 10 angle gauge.

Essentially this index simulates a point sampling (the subject tree being the center point) of all neighboring trees that fall within a BAF 10 prism sweep, weighting the sampled tree's influence as a function of its distance and size relative to the subject tree. The use of a BAF 10 angle gauge is a modification of the original Hegyi index, which used a fixed IO-ft. search radius for competitors.

The maximum diameter attainable for any tree in the stand is assumed to be equal to that attainable for open-grown trees of the same age and height as the subject tree. The following formula, based on a sample of open-grown trees, is used to predict this maximum d.b.h.:

$$DMAX(A, H) = B_1 + B_2H + B_3A \quad (4)$$

where:

- $DMAX(A, H)$ = maximum d.b.h. of open-grown tree at age A with total height H.
- H = total height in feet
- A = total age in years
- B_1 = -2.422297
- B_2 = 0.286583
- B_3 = 0.209472

The first difference with respect to age of the above equation yields the maximum attainable diameter increment for any tree in the stand of height H for any yearly increment A1 to A2 (i.e. AS-Al-l):

$$PDIN(A1,A2) = B_1 + B_2(HIN(A1,A2)) \quad (5)$$

where:

- $PDIN(A1,A2)$ = predicted maximum potential diameter increment in the period A1 to A2.
- $HIN(A1,A2)$ = predicted actual height increment in the period A1 to A2.
- B_1 = 0.209472
- B_2 = 0.286583

This potential diameter increment is then adjusted in the following formula to yield the predicted diameter increment for any given tree in the stand:

$$DIN(A1,A2) = [B_1 + B_2(CL)^{B_3}e^{B_4(CI)}] \times PDIN(A1,A2) \quad (6)$$

where:

- $DIN(A1, A2)$ = actual diameter increment of subject tree for period A1 to A2.
- $PDIN(A1, A2)$ = maximum potential diameter increment of subject tree for period A1 to A2.
- LC = live crown ratio of subject tree.
- CI = competition index of subject tree.
- B_1 = 0.08652
- B_2 = 0.20178
- B_3 = 1.79998
- B_4 = -1.32061

Finally, a random or stochastic element is added to both HIN and DIN to simulate individual-tree departures from predicted growth due to microsite and genetic variation.

The modified model.--Of the six growth eauations in PTAEDA, the fundamental growth regulator is the "maximum height growth potential" of any tree defined by equation 1. This potential for height growth is assumed to be the same for all trees in the woodsrun plantation and is derived from the expected height growth over time for dominant and codominant woodsrun trees on the site; The controlling parameters of the height growth potential are SI and B of equation 1, which together quantify the site index curve and allow the prediction of dominant-codominant height growth.

Genetic improvement of growth should be reflected in an increase in height growth potential compared to woodsrun. For a given planting site, the expected increase in height growth potential of improved stock should be reflected in either an increase in site index (SI) with respect to woodsrun, or a change in the form of the site index curve (B) compared to that of woodsrun, or both. For example, a given planting site on which woodsrun trees have an expected site index (age 25) of 60 feet might be expected to produce a site index of, for example, 65 feet when planted with an improved family. Likewise, the form coefficient (B) might also be expected to change from -5.86537 (the standard for woodsrun in PTAEDA) to, for example, -4.65, reflecting an accelerated early height growth rate of improved stock compared to woodsrun. Previous work (Nance and Wells 1980) has shown that at least for certain types of genetic improvement, both the site index and the form of the site index curve may be affected.

Of course, other growth components could also be affected by genetic selection. However, the dominant role of equation 1 in PTAEDA suggests that modifications to other components beyond equation 1 would produce relatively minor additional effects compared to those brought about by modifying equation 1. In any event, essentially no experimental data is available to suggest what changes, if any, would be required in the remaining growth components.

The situation is more complex when modifications required for the simulation of mixed plantations are considered. First, each family in the mix could have a different height growth potential -- requiring a different SI and B for equation 1 for each family in the plantation. This is easily accomplished by the following modification of equation 1:

$$PHIN_i(A1, A2) = HD_i(A2) - HD_i(A1) \quad (7)$$
$$= [(SI_i)10^{-B_i(1/\sqrt{A1}^{1/} - 1/\sqrt{25})}]$$
$$-[(SI_i)10^{-B_i(1/\sqrt{A2} - 1/\sqrt{25})}]$$

where:

$PHIN_i(A1, A2)$ = potential height increment from age A1 to age A2 for the ith family.

$HD_i(A1)$ = predicted mean height of dominant and codominant trees of the ith family growing in a pure stand at age A1.

$HD_i(A2)$ = predicted mean height of dominant and codoninant trees of the ith family growing in a pure stand at age A2.

SI_i = site index of the ith family in a pure stand on this planting site at index age 25.

B_i = form coefficient for the site index curve of the ith family grown in a pure stand on this planting site. The form of the site index curve is assumed to be:
$\log_{10}(HD) = a + B_i(1/\sqrt{A})$

In this equation, trees from different families are given different height growth potentials, and these potentials are determined by the-performance of individual families in pure stands on the same site.

A second consideration is the interaction between trees from different families when competing In the same stand. The competitlon index, as defined in equation 3, dictates an inherent interaction between trees of different sixes but does not specifically allow genotype by genotype interactions beyond that implied by size differences. However, since equation 7 allows the expression of genetic potential in terms of size differences, then the existing competition index equation will automatically produce interactions between families in the stand. In this sense, genetic Interaction is accomplished without modifying the competition model. Whether or not families could be expected to interact in more specific ways over and above that brought about by size differences is unknown.

Likewise, it is assumed that the other growth equations in the system do not require direct modification due to their heavy dependence on equation 7. Under the above assumptions, then, the only fundamental modification required in PTAEDA's growth relationships to allow for the simulation of mixed plantings is the substitution of equation 7 for equation 1.

The other modifications to PTAEDA were mainly restricted to subroutine PLANT, and simply involved modifications to vary the number of families to be planted, the number of trees per acre to be planted from each family, and the spatial arrangement one to another within the planting. Of course, numerous modifications were made to other subroutines in PTAEDA to keep up with identity and growth characteristics of each family (i.e., estimates of SI and B in equation 7 for each family) as well as the location and family identity of each tree in the stand. This modified form of PTAEDA was named LOBMIX.

THE SIMULATION EXPERIMENT

The classic approach to mixing experiments in crops is the DeWit (1960) replacement series experiment. In this experimental approach, genetic entities (families, varieties, etc.) are grown in pure stands and in binary mixes where the

1/ The addition of the square root operator in this equation is an alternative form of the site index model preferred by the author.

proportion of each entity in the mix is varied systematically -- usually in the three proportions 1:3, 1:1, and 3:1. The results of such experiments allow quantification of the effect of mixing on yields and the prediction of the performance of untested mixes knowing only the monotype performance of the desired components.

The LOBMIX program is capable of simulating a DeWit replacement series experiment in loblolly pine. Basically, it is necessary to estimate the expected performance (i.e., expected SI_i and B_i of equation Ia) of each family grown in pure stands on the prospective planting site. Once these are provided, the program allows mixing of one to ten families in any proportion. The program will then simulate the growth and development of such mixes and provide detailed outputs comparing the relative contribution of each component to the total stand yield.

A hypothetical set of five "families" was chosen as the basic set to be mixed. These families differ in both site index potential and in the form of their site index curves (i.e. $\log_{10}(HD) = a + B(1/\sqrt{A})$) as detailed below:

Family	SI	B
1	68	-2.90
2	70	-2.66
3	67	-2.83
4	66	-2.60
5	58	-2.39

The values for SI and B for each family were suggested by seed source data presented in Nance and Wells (1980).

The ten binary combinations of these five families were simulated in three mixing proportions, 1:3, 1:1, and 3:1. The spacing was 6 x 10 ft. (726 trees per acre), and the trees from each family were randomly assigned to each planting space (i.e., a blend). The growth of the five families in pure stands was also simulated. Hence, there were 35 different simulated stands. The stands were "grown" to age 25 with no thinning, fertilization or site preparation options chosen.

Due to the stochastic components in LOBMIX, each time a particular stand is simulated, different results are obtained. This inherent variation was built into PTAEDA (and hence in LOBMIX) by its developers to simulate natural biological variation in stand development. For this experiment, each simulation of a particular stand was simply labeled a "replicate". Each of the 35 stands was replicated 5 times.

The entire simulation experiment was executed on a small minicomputer and took slightly more than 100 hours of central processor time.

ANALYSES

The volume of each tree in each stand at age 25 was computed using the following equation (Daniels and Burkhart 1975):

$$V = B_1 + B_2 D^2H \qquad (8)$$

where:

V = total stem cubic-foot volume outside bark.
D = d.b.h. in inches.
H = total height in feet.
B_1 = 0.34864
B_2 = 0.00232

For each of the 35 types of stands, individual tree volumes were totaled and subsequently averaged over the five replicates. In addition, total volumes for each family in each stand were also accumulated and averaged over replications.

One question that always arises when dealing with results from mixing experiments is whether or not the mixed stand yields can be predicted using only the single family yields of the families in the mix. One approach to this question is to assume a simple additive model like the following:

$$\hat{V}_{i+j} = (Z_{ij} \times V_{ii}) + (Z_{ji} \times V_{jj}) \qquad (9)$$

$$= \hat{V}_{ij} + \hat{V}_{ji}$$

where:

$\hat{V}_{i+j}$ = expected volume per acre of a mixed stand of family i with family j.
Z_{ij} = proportion of the mixed stand originally planted with family i.
Z_{ji} = proportion of the mixed stand originally planted with family j.
V_{ii} = volume per acre of a pure stand of family i.
V_{jj} = volume per acre of a pure stand of family j.

V_{ij} = expected volume per acre of family i mixed with family j expressed over the entire area occupied by the mixed stand.

$\hat{V}_{ij}$ = expected volume per acre of family j mixed with family i expressed over the entire area occupied by the mixed stand.

If the model fits, then the yield for any mixed plantation can be predicted if the pure family yields of the component families on the same site is known. This Idea has considerable practical utility because in most seed orchards there are far too many families (upwards of 50) to allow testing of all the binary combinations at just three mixing proportions (there are 3,825 such mixing combinations with 50 families).

Another central issue is whether or not each family in the mix contributes in the expected proportion toward the total volume. If two families are mixed in the planting ratio of 1:1, then each will contribute equally to the final volume of the mixed stand unless one family has some sort of competitive advantage over the other. Willey and Rao (1981) developed a quantitative measure of the relative "competiveness" of one family towards another in binary mixes, which they called the competition ratio. It is defined as:

$$CR_{ij} = \frac{(V_{ij} / V_{ii})}{(V_{ji} / V_{jj})} \times \frac{Z_{ji}}{Z_{ij}} \qquad (10)$$

where:

CR_{ij} = competitive ratio of family i with respect to family j when family i is planted in proportion Z_{ij} and family j in proportion Z_{ji}.

and all other terms are previously defined.

Values of CR_{ij} above 1 indicate that family i has a competitive advantage over family j. Values of CR_{ij} equal to 1 indicate no competitive advantage and Cr_{ij} less than 1 indicate a competitive disadvantage. Note also that the reciprocal of CR_{ij} is CR_{ji}.

RESULTS AND DISCUSSION

The average volumes for the 5 pure stands and their 30 mixing combinations are given in Table 1.

Table 1.--Average volumes per acre for pure family and mixed stands after 25 years.

RECURRENT FAMILY	RATIO	NON-RECURRENT FAMILY 1	2	3	4	5
	1:3		5967	5676	5619	4978
1	1:1	5863	5924	5693	5737	5033
	3:1		5955	5705	5670	5468
	1:3			5669	5571	5062
2	1:1		5790	5764	5879	5286
	3:1			5874	5712	5489
	1:3				5466	4887
3	1:1			5653	5651	5165
	3:1				5534	5360
	1:3					4898
4	1:1				5428	5088
	3:1					5257
	1:3					
5	1:1					4680
	3:1					

The first question that arises when inspecting these results is whether or not the off diagonal entries (mixed stands) can be predicted using the diagonal entries (pure family stands). Formula 9 of the preceeding section is designed for this purpose.

Although the model looks formidable, it is very simple to apply. For example, the volume of the 1:3 mix of Family 2 with Family 5 in Table 1 is 5,062 cubic feet per acre, and the expected volume per acre for this mix under the assumption of additivity is:

$$\hat{V}_{2+5} = 0.25(5,790) + 0.75(4,680)$$
$$= 1,447.5 + 3,510$$
$$= 4,957.5 \text{ cubic feet}$$

The deviation from additivity (i.e. $V_{i+j} - \hat{V}_{i+j}$) for this case is -104.5 cubic feet. The average deviation for the 30 combinations in Table 1 is -18.63 cubic feet with a standard deviation of 96.52 cubic feet and a maximum deviation of 270 cubic feet. The Family 1 by Family 2 mixes consistently produced more volume than expected, whereas the Family 1 by Family 5 mix produced less than expected. Overall, though, the additive model fits quite well, with an R^2 for prediction of 0.91.

At least for these results, then, all the mixed stand yields could be predicted within the indicated error rate using only the single family yields. Moreover, the yield of any binary mix in any proportion could be predicted with this model under the assumption that additivity holds. Finally, the yield of mixes involving more than 2 families in any proportion could also be predicted under the same assumption. Such extensions of the additive model would necessarily require large amounts of empirical evidence.

Another interesting question is whether or not each family contributed as expected to the total volume of the mixed stand. Using equation 9 and the above example, the expected contribution of Family 2 and Family 5 to the total volume of the mixed stand (i.e., V25 and V_{52}) is 1,447.5 and 3,510 cubic feet, respectively. The actual contribution was 2,038 and 3,024 respectively, indicating that in this particular mix, Family 2 fared much better than expected and Family 5 much worse than expected. This outcome might be expected, considering the very large difference in site index potential between these two families.

Applying equation 10 to assess the competitive advantage of Family 2 versus Family 5 yields:

$$CR25 = \frac{(2,038/5,790)}{(3,024/4,680)} \times \frac{0.75}{0.25}$$

$$= 1.63$$

which indicates that Family 2 is indeed expressing a high degree of competitive advantage over Family 5.

The competitive ratios for all the simulated stands is given in Table 2. Family 5 is clearly at a competitive disadvantage when mixed with any other family in the set, especially Family 2. The competitive advantage of Family 2 over Family 5 is expressed most strongly in the mixes where Family 5 is contributing less than 50 percent of the trees -- the CR25 values are 1.63, 1.43, and 1.27 for 1:3, 1:1, and 3:1 mixtures of Family 2 with Family 5. This is apparently due to the trees from the more competitive Family 2 competing against one another more often as the mixing proportion is increased. This trend in competition ratios, however, is not consistent for mixtures involving families other than Family 5.

Table 2.--Competition ratios for components of mixed stands after 25 years.

RECURRENT FAMILY	RATIO	NON-RECURRENT FAMILY 1	2	3	4	5
	1:3		0.83	1.04	1.11	1.23
1	1:1	1.00	0.93	0.99	0.98	1.31
	3:1		0.74	1.01	0.84	1.15
	1:3			1.31	1.11	1.63
2	1:1		1.00	1.12	1.28	1.43
	3:1			1.27	1.33	1.27
	1:3				1.05	1.39
3	1:1			1.00	0.77	1.32
	3:1				0.73	1.14
	1:3					1.51
4	1:1				1.00	1.42
	3:1					1.29
	1:3					
5	1:1					1.00
	3:1					

Those stands representing a mixture wherein one family has a strong competitive advantage over another might be expected to exhibit large size differences between trees from the two families. One way to quantify such a comparison is to compute a ratio of the average volumes per tree for each family in the mix, as shown in Table 3. These ratios Illustrate the marked size differential brought about by the differences in growth potential within a mixed stand. In the 1:3 mix of Family 2 with Family 5 for example, the surviving trees of Family 2 were almost twice as large in terms of individual tree volumes as those from Family 5.

Table 3.--Relative size of trees from each family in mixed stands after 25 years.

RECURRENT FAMILY	RATIO	NON-RECURRENT FAMILY 1	2	3 [1/]	4	5
	1:3		0.89	1.01	1.11	1.45
1	1:1	1.00	1.00	1.06	1.08	1.57
	3:1		0.89	1.12	0.97	1.50
	1:3			1.23	1.12	1.87
2	1:1		1.00	1.07	1.32	1.63
	3:1			1.29	1.30	1.44
	1:3				1.04	1.66
3	1:1			1.00	0.95	1.64
	3:1				0.83	1.53
	1:3					1.50
4	1:1				1.00	1.58
	3:1					1.54
	1:3					
5	1:1					1.00
	3:1					

1/ relative size is expressed as a ratio of the average volume per tree of the recurrent family divided by the average volume per tree of the non-recurrent family in the indicated mix.

CONCLUSIONS

There can be several implications of these results if they are eventually verified by field experiments and more simulations. First, mixing would seem to offer little benefit in terms of increasing total volume production on a site over and above that of the best component family. This result is intuitively appealing and matches that of most crop mixing experiments where the additive model seems to be widely applicable.

Second, there could be beneficial effects of mixing when the control of Individual tree size within the stand is important, such as in the production of merchantable sawlogs or poles. For example, mixtures such as Family 2 with Family 5 in this simulation appear to result in a stand in which trees from the faster growing family (2) benefit from a low level of competition from the slower growing family (5), much as they would if planted at lower densities. However, unlike low density stands, the total volume is quite high because the inferior family still contributes a significant proportion to the total volume produced on the site. Hence trees from the inferior family serve both as "trainers" for the fast growing family and also contribute toward the final volume.

Third, the marked effect of mixing on individual tree size suggests that row plot progeny tests, which are simply multi-family mixes with spatial restrictions, may produce biased estimates of the true yield potential of a given family when planted either by Itself or in different combinations in a mix. For example, in the 1:3 mix of Family 2 with Family 5, the trees from Family 2 in the mixed stand produced 87 percent more volume per tree on an average than those from Family 5. However, in pure family stands the total volume per acre of Family 2 and Family 5 averaged 5,790 and 4,680 cubic feet respectively -- a difference of only 24 percent.

Future work in this area is needed in order to incorporate other important family attributes such as response to competition and disease resistance into the simulator. Competitive interactions between families could have dramatic effects on the performance of mixed stands and should be considered in more detail.

Likewise, the risk from diseases and pests is often a major factor in forest management and the effect of mixing both on the risk to diseases and pests and the subsequent yield losses after infection or infestation should be considered.

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STORMFLOW CHANGES AFTER PRESCRIBED BURNING AND CLEARCUTTING PINE STANDS IN THE SOUTH CAROLINA PIEDMONT[1/]

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Abstract .-Four small pine-covered watersheds in the South Carolina Piedmont were prescribe-burned in September 1979 and clearcut 3 months later. During the next 20 months, highly significant increases in peak discharge and stormflow volume occurred on three of the watersheds. Relative increases as determined by the paired watershed approach were greater than those reported for larger watersheds. The changes were smaller than those to be expected from mechanical site preparation after clearcutting, however. Time to peaking and duration of stormflow were not significantly affected by burning and clearcutting.

INTRODUCTION

Heavy equipment is often used to prepare harvested sites for regeneration of pine in the south. Such treatment often compacts soil and greatly increases soil erosion (Douglass and Goodwin 1980, Ursic and Douglass 1978). Prescribed burning to prepare aeedbeds for natural seeding is an alternative that may be less damaging than mechanical methods. In 1976, a study was begun in the South Carolina Piedmont to evaluate the silvicultural potential and hydrological impacts of low-intensity prescribed burning followed by natural regeneration of loblolly pine (*Pinus taeda* L.) as-an alternative to mechanical site preparation and artificial regeneration. Neither runoff, sediment concentration, nor sediment export was significantly affected by the first two prescribed burns (Douglass and Van Lear In Press). After the third burn, the stand was regenerated by clearcutting with seed in place. Van Lear et al. (this conference) have discussed the silvicultural effects of these treatments. In this paper, we review the stormflow effect of the third prescribed burn followed closely by clearcutting.

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METHODS AND SITE DESCRIPTION

Control and treatment watersheds were replicated at four locations on the Clemson Forest in a randomized complete block design. This arrangement also allows responses at each location to be examined by the paired watershed approach.

The watersheds are on uplands and range from 1 to about 5.3 acres in sise (Table 1). All were in row crops prior to establishment of loblolly pine plantations nearly 40 years ago. Soils are Typic Hapludults. They are well drained and highly weathered soils derived from granite and gneiss. Much of the original surface layer was washed away during decades of row cropping. Typically, the surface soil of upper slopes is a sandy loam plow layer of variable depth overlaying a slowly permeable, clay B horizon. Because of differences in the conservation practices applied and erosion during the agricultural period, the physical conditions of the watersheds are quite variable. Some still have recognizable terraces with little visible sign of erosion and short channels. Others have extensive ephemeral channel systems formed by inactive gullies remaining after farming. Upper slopes Showed least signs of past erosion, whereas middle and lower slopes were more severely eroded.

Air temperature of the sites ranges from a mean of 38° F in January to 80° F in July. Annual rainfall in the Clemson area averages 51 inches and is well distributed throughout the year. Thirty percent of the rainfall occurs in winter, and runoff is normally greatest in that

Table 1 .--Characteristics of study watersheds 1/

Watershed	Size	Slope	Length of uninterrupted channel above flume	Soil series	Basal area of loblolly pine
	ac	%	ft		ft^2/ac
61-Treated	1.6	13	75	Cecil, Madison	143
62-Control	3.8	19	39	Pacolet, Madison	191
63-Control	5.4	13	46	Pacolet	65
64-Treated	2.8	16	16	Pacolet	97
65-Control	1.0	10	324	Pacolet	82
66-Treated	3.1	11	676	Pacolet	78
67-Control	1.2	12	384	Cecil, Madison	104
68-Treated	1.5	12	571	Madison	100

1/ All plantations were 36 years old at the beginning of the study except Watersheds 61 and 62 which were 37 years old. Watersheds 63 end 68 had previously been thinned one or more times.

season. Because the study watersheds are small upland drainages, all flow occurs only during and for a short time after substantial rain storms.

Runoff from each watershed was measured with a l-foot H-flume attached to a plywood cut-off wall embedded in the gully channel. Flow was recorded by an analog-to-digital punch tape recorder. Flow volumes in cubic feet/second/square mile (csm) were calculated by the procedures described by Hibbert and Cunningham (1967).

Watershed calibration began in June 1976. The first prescribed burn was on March 11, 1977, 3 days after a cold front delivered about 0.8 inch of rain. Air temperature was about 50° F, relative humidity varied from 35 to 50 percent, and windspeed ranged from 5 to 10 miles per hour. The burning technique was to backfire along the upper ridge and then ignite strip headfires at about 30-foot intervals. Burning intensity varied considerably among watersheds, but each watershed was burned entirely. Flame heights averaged about 1 foot on Watershed 68 and about 3 feet on Watersheds 64 end 65, the last two burned. The second burn was on September 20, 1978, about 2 weeks after a rain. The same burning technique was used but fires were less intense because less fuel was available. Air temperature ranged from 78° to 90° F, relative humidity varied from 38 to 50 percent, and windspeed was about 10 miles per hour. The third burn was on September 12, 1979, to prepare a seedbed prior to harvest of timber. Relative humidity ranged between 55 and 60 percent, temperature was in the 80's, and a 10 mile per hour breeze fanned flames to an average height of 1 foot. Overall, it was the coolest of the three burns.

Prior to burning, litter weight on the watersheds was about 11 tons per acre. The first burn consumed the most litter and the third burn the least. After the third burn, 7½ tons per acre of protective litter remained.

Timber harvest began in December 1979 and ended in mid-January 1980. During logging, care was exercised to prevent unnecessary damage to the soil and litter. Logs were skidded uphill to a landing and loaded on trucks. Logging slash was left in place on Watersheds 61, 66, and 68. On Watershed 64, slash was bladed off the watershed with a bulldozer to simulate whole-tree harvesting. This treatment approximately doubled the exposure of mineral soil on the watershed.

Previous analyses indicated no significant effect of the first two prescribed burns on water yield or stormflow (Douglass and Van Lear In Press). Therefore, flow data for the calibration period end the first three burns (June 1976 until December 1979) were combined for Watershed pairs 61-62, 63-64, and 65-66. However. Watershed 68 experienced an outbreak of the southern pine beetle (*Dendroctonus frontalis* Zimm.) after the first burn and by October 1978, 20 percent of the pine basal area-was dead. Most of the mortality occurred along the ephemeral channel in the lower portion of the watershed. The calibration period for this watershed pair waa from June 1976 until October 1978. The treatment period was the 21 months from February 1980 through October 1981.

The earlier analysis revealed large differences in runoff volumes between locations. Because the paired watershed method provides greater precision in comparing treatment effects, it waa used to determine effects of treatment (Hewlett et al. 1969). Treatment is defined as the combined effect of the third burn and clear-cutting. With the paired watershed method, the characteristic of interest for the calibration period on the watershed to be treated is regreased against the same characteristic on the control watershed. After calibration, the difference between the observed value and the value predicted for the treatment watershed using the calibration regression is taken as the treatment effect.

The technique of Hibbert and Cunningham (1967) waa used to divide the storm hydrograph into parametera for testing (Figure 1). Total runoff is separated into several hydrograph parameters and total flow is divided into base-flow and stormflow volume. The flow parameters examined in this study were:

Qp	peak rate of runoff
qi	flow rate of the beginning of the runoff event
v_1	volume of storm runoff before the peak
v_2	volume of storm runoff after the peak
$v_1 + v_2$	total volume of storm runoff
Tp	time to peak, the time in hours from the beginning of storm runoff to peak runoff
R	recession time, the time in hours from the peak runoff rate to the intersection of the separation line and the hydrograph recession line
D	time in hours from the beginning of runoff until the time of intersection of the recession hydrograph and the separation line.

Storm events were selected for analysis if both watersheds had minimum flows of 10 cam and single peak hydrographs.

Statistical significance was determined by the procedure described by Gjarati (1970) and Swindel (1970) of testing the equality of sets of linear regression coefficients. The treatment period is handled as a dummy variable, and the differences between pretreatment and post-treatment slopes and intercepts are tested using the F atatiatic.

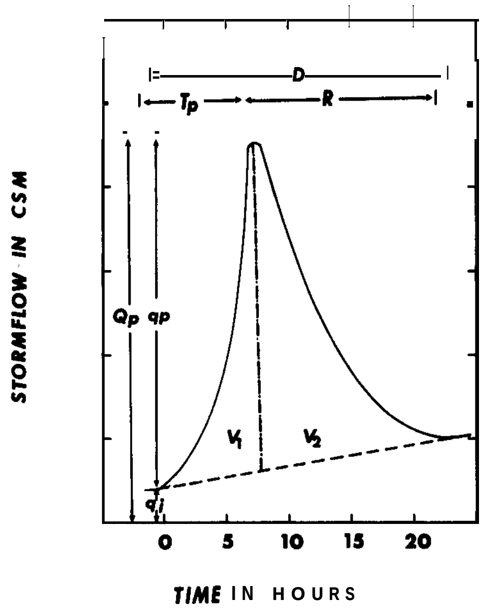


Figure1 .--Schematic representation of the computer separation of the storm hydrograph into parameters susceptible to statistical analyses.

RESULTS AND DISCUSSION

Earlier findings on these watersheda indicated that, although the first two prescribed burns did not significantly affect storm runoff, large variation in runoff aid occur between aome watershed pairs and between some locations (Douglass and Van Lear In Press). Greatest variation was between the Watersheds 61-62 pair. Treated Watershed 61 had a large atone terrace or check dam about 75 feet upstream from the flume. Several cubic yards of sandy loam colluvial material were deposited behind this erosion control structure and provided appreciably more storage than was available on Watershed 62. Frequently, small storms would produce runoff from Watershed 62 but none from Watershed 61. During large storms, flow from Watershed 61, because of the enlarged storage capacity, would continue for a longer period than would flow from Watershed 62. Theae factors caused poor correlation between storm hydrograph parameters for Wateraheda 61 end 62, and only four events were available for inclusion in the treatment period (Figure 2). Therefore, this watershed pair waa excluded from the complete analysis.

Length of the ephemeral channel network also differed within waterahed pairs and between locations. The average fraction of rainfall that became streamflow increased with length of uninterrupted channel on the eight watersheda during the calibration period and varied from about 5 to 17 percent. A regression of the fraction of rain that became streamflow against the length of uninterrupted channel had an r of 0.86.

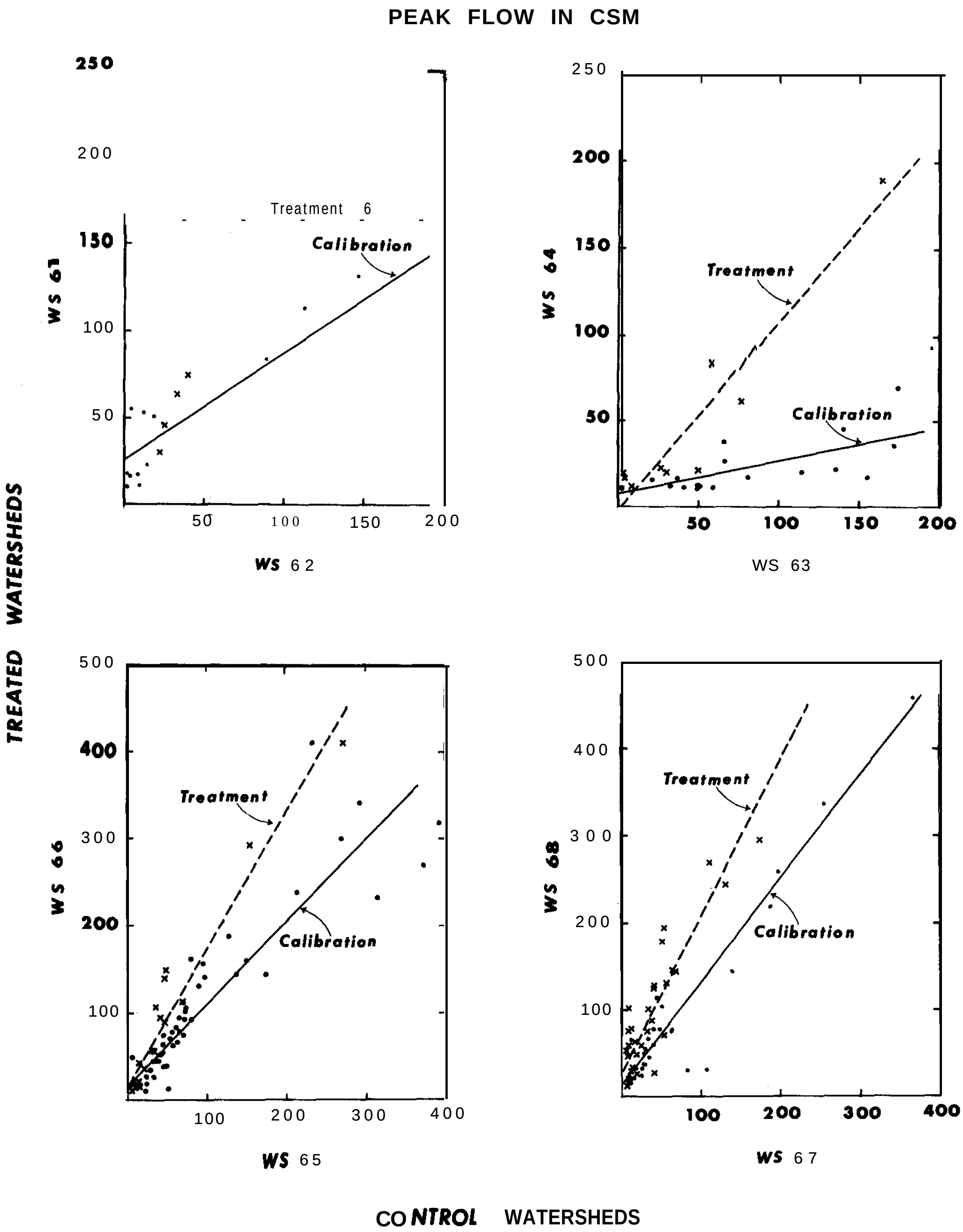


Figure2 .--Peak discharge in csm during the calibration (.) and treatment (x) periods for the four pairs of watersheds.

Results from the stormflow analysis for treated Watersheds 64, 66, and 68 were consistent except for the initial flow rate, which is the flow at the beginning of the storm. This parameter has little meaning for watersheds of this siee because there is no flow at the beginning of most storms. There was no increase in initial flow rate due to treatment on Watersheds 64 and 66 and the increase on Watershed 68 was barely significant at the 0.05 level.

Time to peak and flow duration were unaffected by treatment. Burning and clearcutting significantly increased peak flow, stormflow volume before the peak, stormflow volume after the peak, and total stormflow volume at the 0.01 level (Table 2).

Table 2.--Effects of prescribed burning followed by harvesting timber by clearcutting on increasing stormflow[1/]

Stormflow parameter	Watershed number 64	66	68
Initial flow rate	NS	NS	*
Peak flow rate	**	**	**
Time to peak	NS	NS	NS
Storm duration	NS	NS	NS
Stormflow volume before peak	**	**	**
Stormflow volume after peak	**	**	**
Total stormflow volume	**	**	**

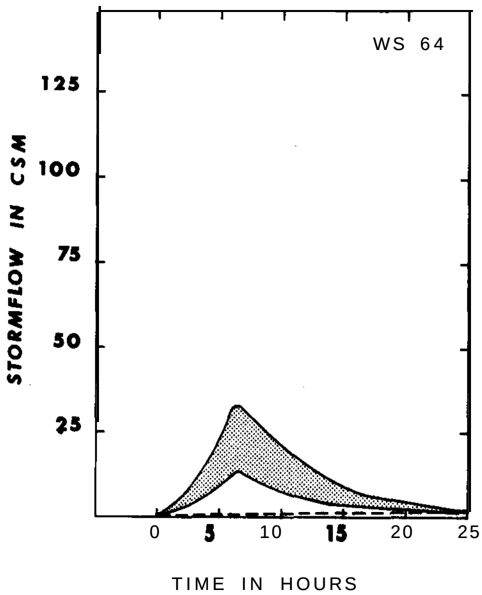
1/ NS = nonsignificant;
* = is a significant increase at the 0.05 level; and
** = is a significant increase at the 0.01 level.

The calibration and treatment regression lines for peak flow for the four pairs of watersheds are shown in Figure 2. As previously noted, only four observations were available for Watersheds 61 and 62 during the treatment period and these were judged insufficient for valid statistical tests on this watershed pair. The increase in peak flow due to treatment as a percentage of pretreatment peaks was greatest on Watershed 64. Note, however, that absolute discharges were greater before and after treatment on Watersheds 66 and 68.

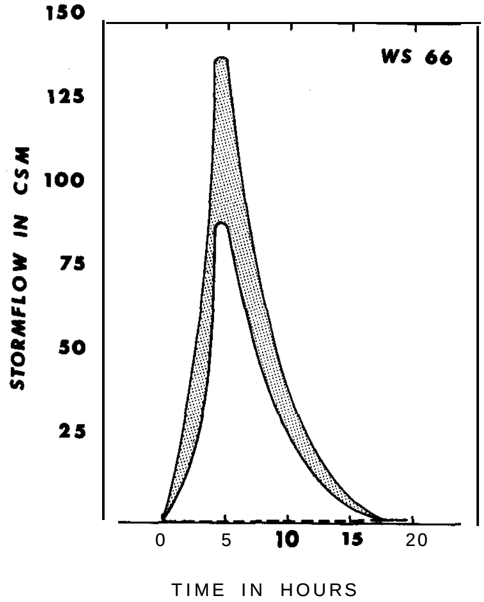
The effects of the third prescribed burn and clearcutting on the mean storm hydrograph are illustrated for the three watersheds in Figure 3. Because the scale is the same, relative differences in storm hydrographs between the pairs of watersheds can be judged visually. Watershed 64 obviously responds to precipitation differently from Watersheds 66 and 68, both before and after treatment. Peaks are smaller, time to peak is greater, end the duration of stormflow is 75 percent longer than on Watersheds 66 end 68. The average storm hydrograph for Watershed 64 (Figure 3a) is indicative of a stable watershed where most precipitation infiltrates end slowly drains from the watershed. Surface soil of Watershed 64 is deeper and more porous than that of Watersheds 66 and 68. Therefore moisture storage is greater, leading to smaller peaks and more prolonged flow. Treatment increased the average peek discharge over 150 percent and approximately doubled stormflow volumes on Watershed 64, about three times'the percentage increase on Watersheds 66 and 68. This large increase may have been caused by the greater site disturbance when the logging slash was bulldozed off this watershed to simulate whole-tree harvesting. Mineral soil was exposed on about 50 percent of Watershed 64 compared to only 20 to 25 percent on Watersheds 66 and 68. Exposing mineral soil on 50 percent of the area during mechanical site preparation has been shown to greatly increase storm runoff in the Piedmont (Douglass and Goodwin 1980) and Coastal Plain (Beasley 1979).

Peaks for the mean storm on Watersheds 66 and 68 were increased by 55 to 60 percent (Figure 3b and c). The percentage increase in peaks after treatment was less for these watersheds than for Watershed 64, but the pretreatment peaks were about 7 times greater; thus, initially they were much more responsive to rainfall. The greater responsiveness is attributed to the general hydrologic characteristics of eroded Piedmont soils and the greater dissection of Watersheds 66 and 68. Typically, former agricultural soils have a permeable sandy loam to loam residual plow layer that is limited in moisture storage capacity. A dense, slowly permeable B horizon lies beneath the plow layer and severely restricts vertical drainage (Hoover 1950). Because rates of rainfall often exceed the percolation rate of the B horizon, the plow layer becomes partly or completely saturated. On sloping land, the predominate flow path of water is downslope at the top of the B horizon. Where past erosion has exposed the B horizon and interrupts subsurface flow, free water enters the ephemeral drainage. The denser the channel or gully network, the shorter the subsurface flow path and the more rapid the storm runoff.

Because earlier analyses indicated no significant direct effect of prescribed burning on water yield, we suggest that it is unlikely that the third burning significantly affected stormflow characteristics. More likely, treatment effects resulted from the harvest and removal of timber from the site. A modest increase in both peak flow rates and volumes of stormflow is normal in the Appalachians when the forest is clearcut end felled trees are left in place (Hewlett and Helvey 1970). When felled trees are skidded, the increases are usually larger (Douglass and Swank 1976, Swank et al. In Press, Lynch 1969, Beinhart et al. 1963). The size of the effect depends on the care exercised during road construction and skidding operations.

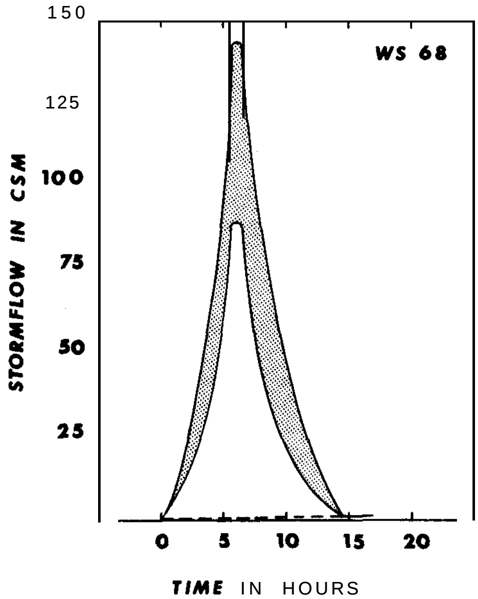


a



b

Figure3 .--Graphic representation of the average storm hydrographa for the calibration and treatment periods for Watersheds 64, 66, and 68. The shaded area indicates the change associated with the prescribed burn-clearcut treatment.



C

In general responses to the burning and clearcutting treatment are much leas than responsea to mechanical site preparation practices in the Piedmont (Douglass and Goodwin 1980) and steep Coastal Plain watersheds (Beasley 1979). Mechanical treatments have increased stormflow volumes 3- to 18-fold, depending on the particular practice involved.

Interpretation of our data in relation to the larger bulk of the literature on timber harvest is difficult because of the uncertanties associated with watershed size. Magnitude of increases in both peak rates end stormflow volumes on our small Piedmont watersheds exceeded by a factor of 2 or more the responses observed on larger Appalachian watersheds and on a larger Piedmont watershed which was roaded, clearcut, roller chopped, end planted (Hewlett 1979). Our watersheds are 1 to 5 acres in size, as exe moat watersheds on which site preparation responses have been measured. Moat past studies of harvesting effects, however, have been on watersheds covering from 30 to over 300 acres. Differences in basin hydrology and possibly watershed size influence the response. Moat studies on larger watersheds measure, or are assumed to measure, total flow, whereas only quick return subsurface and overland flow were measured in our study. The greater storage potential of large watersheds may explain, at least in part, the difference in hydrology of small versus large basins.

Although there may be uncertainties as to whether results from very small and larger watersheds are directly comparable, clearly stormflow was significantly increased by the treatment applied. From past experience, we would expect higher peaks end greater stormflow volumes from clearcutting the watershed, end we would expect the magnitude of the response to be proportional to the degree of site disturbance. Thus, findings from our watersheds are consistent with findings from other cutting experiments.

We conclude that the effects on peak flow and stormflow volume of prescribed burning for seedbed preparation followed by clearcutting with seed in place were much less severe than effects reported for mechanical methods of site preparation. A review of agricultural history of the Piedmont clearly indicates the sensitivity of these soils. It appears only prudent to recognize this sensitivity and to carefully weigh the impact of operations on the hydrologic functioning of these lands. Hydrologically, silviculturally, and economically, the method proved to be a viable and desirable regeneration technique in this study.

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SEDIMENT LOSSES FROM FOREST PRACTICES IN THE GULF COASTAL PLAIN OF ARKANSAS[1]

R. Scott Beasley and Alfredo B. Granillo[2]

ABSTRACT. -- During the first year after clearcutting and intensive mechanical site preparation, mean annual stormflows and sediment losses were significantly higher than levels measured on watersheds which were selectively harvested or left undisturbed. Results are compared with data reported for other locations in the South, and water quality implications are discussed.

INTRODUCTION

Much of the southern pine range on the Gulf Coastal Plain consists of relatively flat terrain (slope gradients of O-3 percent). These sites generally have high site indices for pine especially if drainage is not excessively poor (Coile 1952, Zahner 1957, Barrett 1962). Because of its high productivity, the region has excellent potential for supplying a large share of the nation's growing demand for wood products. The forest acreage owned by private companies in the South is already under intensive management. As the profitability of growing trees increases many non-industrial private landowners may also be encouraged to opt for more intensive management on their forests which collectively account for about 72% of forest acreage in the South (U.S.D.A. 1978).

As the level of management intensifies the potential for erosion and stream sedimentation increases. Historically priority has been given to evaluating the water quality effect of silvicultural treatments on sloping terrain where the velocity and sediment carrying power of storm runoff are greater. Little attention has been given to the water quality impacts of intensive management on gentle slopes. Now, more than ever, forest managers need accurate information for a wide range of site conditions to maintain site productivity and protect water quality. This study contrasts soil losses from a series of forested watersheds on relatively flat terrain that were either: (1) clearcut, site prepared, and replanted to pine, (2) selectively harvested to achieve an uneven-aged pine stand, or (3) left undisturbed to serve as controls. Data are presented for the first full water-year (WY 1982: July 1, 1981-June 30, 1982) after the silvicultural treatments were begun.

METHODS

The watersheds are located on the Gulf Coastal Plain of southeastern Arkansas near Monticello, Drew County. Six watersheds (Ten Mile Creek site) are on property owned by the Georgia-Pacific Corporation and three watersheds (Hungerrun Creek site) are located on land owned by the International Paper Company. All watersheds in each group are within a 1/4 mile radius. The two groups of watersheds are approximately six miles apart.

Prior to treatment the overstory vegetation at the Ten Mile Creek area had a higher proportion of hardwoods than the Hungerrun site. White oaks (Quercus alba L. and Q. stellata Wangenh.), southern red oak (Quercus falcata Michx.), sweetgun (Liquidambar styraciflua L.), and hickories (Carya sp.) were the predominant hardwood species. Loblolly pine (P. taeda L.) and shortleaf pine (P. echinata Mill.) were found in roughly equal proportions on the Ten Mile Creek site, but loblolly pine clearly dominated at the other site. Slope gradients range from 1 to 3%, with an average of about 1%. The dominant soil series on the watersheds is

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Tippah silt loam, a fine-silty, mixed, thermic Aquic Paleudalf (Larance, et al. 1976).

Measurements

Vegetation

Before treatment the sawtimber and pulpwood volumes of each watershed were inventoried. All trees with an average dbh ≥ 3.5 in. were measured. Local volume tables were used to compute board feet of sawtimber (dbh ≥ 9.5 in.) and cubic feet of pulpwood (3.5 in. $\leq$ dbh < 9.5).

Twenty one-chain transects were randomly located on each of the clearcut watersheds to characterize ground cover after treatment. Ground cover under each link was recorded as either bare soil, rock, litter, woody debris, or type of vegetation.

Precipitation

Precipitation amounts w re measured in a network of standard rain gauges at each site. Intensities and durations were obtained from Belfort weighing bucket recording gauges.

Stormflow

The volume of runoff from each watershed was measured with a 3 ft. H-type flume equipped with an automatic water level recorder. A drop-box was constructed at the upper end of the approach section to collect non-suspended or bed-load materials. Because of the flat terrain, concrete wing walls were constructed at the lower section of each watershed to prevent surface runoff from bypassing the flumes. Stormflow was expressed as depth of water over the watershed area to conform to precipitation measurements.

Sediment

Water samples were collected by Coshocton sediment samplers placed below the flumes. Water collected by the samplers was further divided by slotted splitters. Samples were vacuum filtered to measure the concentration of sediment (ppm). Total suspended sediment for each storm event was determined by multiplying concentrations by stormflow (discharge) volumes. Oven-dry weight of deposited sediment from the traps was added to suspended sediment to give total sediment loss per storm (lbs). These values were divided by watershed size and expressed as lbs/ac. Total sediment losses (deposited plus suspended) were then divided by total stormflow volume (discharge-weighted) and expressed as concentrations (ppm).

Design and Treatments

Precipitation, stormflow, and water quality were measured on all nine watersheds for one full year before treatments were imposed (Beasley 1982). The watersheds ranged in size from 5.61 to 10.00 ac. To facilitate statistical analysis the watersheds were grouped into blocks of three, based on location and local variations in soils, slope, and/or vegetation. Each watershed in each block received a different silvicultural treatment. The treatments were: 1) clearcutting followed by shearing, windrowing, burning and replanting with loblolly pine seedlings, 2) selective harvesting including the removal of all commercial hardwoods and the deadening by injection of all remaining hardwoods, 3) and the undisturbed controls. The sawtimber volume to be removed from the selectively harvested watersheds was determined by a regulation method designed to achieve a balanced uneven-aged stand (Farrar 1980).

Harvesting began in July 1981 and was completed by mid-August. Site preparation on the clearcut watersheds was completed in September. Seedlings were hand planted in early 1982.

A randomized complete block analysis of variance was used to evaluate differences in stormflows, sediment losses and concentrations for the three treatments. Duncan's New Multiple Range tests were used to compare individual treatment means.

RESULTS AND DISCUSSION

Vegetation

Sawtimber (pine and hardwood) board foot volumes on the experimental watersheds before treatment ranged from 5,589 to 11,251 bdft/ac; pine and hardwood pulpwood volumes ranged from 7.6 to 19.5 cords/ac (Table 1). Basal area on the selection watersheds was reduced to an average of 48 $ft.^2/ac.$

Clearcutting and site preparation exposed bare soil on 66.4%, 36.4% and 39.6% of watersheds 1,5 and 9, respectively. Bare soil exposure was highest on watershed 1 because the site was wettest during site preparation. This reduced shearing efficiency requiring several passes to sever many of the larger stumps. This caused deep rutting in some areas.

Precipitation and Stormflow

Precipitation for the post-treatment water-year averaged 47.93 in. (Table 2). The long term mean precipitation for the study area is 51.80 in. Thirty-three rainfall events produced measurable stormflow ($\geq .01$ in.) on at

Table 1. Sawtimber and pulpwood volumes (pine and hardwood combined) on experimental watersheds before and after harvest.

Watershed by Treatment	Before Harvest		After Harvest		Volume Harvested	
	Sawtimber bf/ac	Pulpwood cds/ac	Sawtimber bf/ac	Pulpwood cds/ac	Sawtimber bf/ac	Pulpwood cds/ac
Clearcut						
1	9,013	9.0			9,013	9.0
5	9,218	12.4			9,218	12.4
9	6,167	19.5			6,167	19.5
Selection						
2	9,284	7.9	3,628	4.6	5,656	3.3
4	11,251	10.8	3,408	5.2	7,843	5.6
8	6,849	18.8	3,863	8.5	2,986	10.3
Control						
3	8,285	7.6	8,285	7.6		
6	8,304	11.7	8,304	11.7		
7	5,589	13.1	5,589	13.1		

Table 2. Monthly rainfall (in) and stormflow (in) by watershed and treatment for WY 1982. Rainfall values are averages of all standard gauges.

Month	Rainfall	Clearcut			Selection			Control		
		1	5	9	2	4	8	3	6	7
July	3.82	T	0	T	0	T	T	T	0	0
Aug	3.00	T	T	T	0	0	0.01	T	T	T
Sept	5.21	0.03	T	0.01	0	0	0.01	T	T	0.01
Oct	7.15	1.95	0.94	1.15	0.05	0.18	0.49	0.01	0.01	0
Nov	1.85	0.37	0.11	0.11	0	0	0.13	0	0	0
Dec	0.60	T	0	0	0.02	0	0'	0	0	T
Jan	4.35	0.73	0.37	0.48	0.21	0.24	0.29	0.02	0	0.11
Feb	3.94	1.85	0.93	0.88	0.64	0.71	0.61	0.11	0.02	0.70
Mar	1.76	0.18	0.10	0.09	0.04	0.09	0.02	0.01	T	0.11
Apr	4.46	0.52	0.20	1.44	0.14	0.26	1.00	0.03	T	0.75
May	4.11	0.55	0.42	0.23	0.04	0.17	T	T	T	T
June	7.66	0.91	0.61	1.46	0.20	0.28	0.87	0.01	T	0.04
TOTALS	47.93	7.10	3.68	5.85	1.34	1.94	3.43	0.20	0.03	1.71
ANNUAL AVG. by TREATMENT			5.54 a[1]			2.24 b			0.64 b	

[1] Treatment means with same letter designations are not significantly different (p=.05)

least one of the clearcut watersheds; twenty-four produced flow on the selectively harvested watersheds; sixteen produced flow on the control watersheds. Precipitation, almost entirely in the form of rain, was fairly well distributed throughout the twelve month period except for November and December 1981 and March 1982 which were low. Stormflows were low to negligible on all watersheds during the first half of NY 1982 (except October) and March.

Mean annual stormflow on the clearcut watersheds was significantly higher than either the selection or control watersheds (Table 2). However, the difference in mean annual stormflow between the selection and control watersheds was not statistically significant. Stormflow as a percentage of total annual precipitation was 12% for the clearcut watersheds, 5% for the selection watersheds and 1% for the control watersheds. Reduced evapotranspiration leads to higher soil moisture: hence, less storage capacity and greater runoff (Hornbeck 1975, Douglass and Swank 1972).

Sediment

First-year mean sediment losses on the clearcut watersheds were significantly higher than those on the selection and control watersheds (Table 3). However, there was no significant difference between annual losses on the selection and control watersheds. Although clearcutting and mechanical site preparation significantly increased sediment losses from the experimental watersheds the increase was not as large as those reported in other sections of the Gulf Coastal Plain. Beasley (1979) reported first-year sediment losses of 11,188, 11,420 and 12,714 lb/ac from three clearcut watersheds with steep slopes and erodible soils in north Mississippi which had been mechanically site prepared. DeHaven et al. (1982) measured an average of 2203 lb/ac of sediment in only eight months on three clearcut watersheds in east Texas which were site-prepared by shearing, windrowing and burning. Slope gradients ranged from 4% on the hilltops to 25% on the side slopes. Douglass and Goodwin (1980) reported first-year mean

Table 3. Monthly sediment losses (lbs/ac) by watershed and treatment for WY 1982.

	Clearcut			Selection			Control		
Month	1	5	9	2	4	8	3	6	7
July	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0
Sept	0	0	0.1	0	0	0.3	0	0	0
Oct	140.9	62.6	2.9	0	0	0.8	0	0	0
Nov	4.8	1.4	0.9	0	0	0.9	0	0	0
Dec	0	0	0	0.5	0	0	0	0	0
Jan	37.9	52.3	24.6	6.8	4.3	1.1	0.2	0	0
Feb	70.1	69.8	70.2	1.9	2.6	3.1	0.4	0	7.8
Mar	2.5	0.6	0.1	0.1	0.6	0	0	0	0
Apr	19.5	6.7	90.1	1.0	1.4	2.9	0.2	0	2.6
May	6.8	9.6	0.9	0.1	0.4	0	0	0	0
Jun	16.6	10.6	6.6	1.4	1.7	3.5	0.1	0	0.1
TOTALS	299.1	213.7	196.5	11.9	11.0	12.6	1.0	0	10.5
ANNUAL AVERAGES BY TREATMENT		236.4 a			11.8 b			3.8 b	

sediment losses of 4,480 lbs/ac from four clearcut, sheared, windrowed, and burned watersheds in the North Carolina Piedmont.

Sediment losses accumulated by months closely paralleled accumulated stormflows for all treatments (Figure 1). Stormflows and sediment losses began to rise on the clearcut watersheds in October 1981; on the selection watersheds in January 1982; and one month later on the control watersheds. The time lags from initiation of stormflow and sediment production between treatments is further evidence of reduced water storage capacity and faster moisture recharge on the clearcut areas.

Three storms accounted for most of the annual sediment losses from all watersheds; 74% to 87% for the clearcut watersheds; 55% to 81% for the selection watersheds; 76% to 93% for the control watersheds. Other studies (Greer 1971, Beasley 1979) have shown similar results, indicating that large storm events have a disproportionate effect on erosion and sedimentation.

Annual discharge-weighted sediment concentrations generally provide an acceptable basis for contrasting sediment losses among watersheds and treatments with differing annual stormflow regimes (Ursic 1979). Mean annual sediment concentrations were significantly higher on the clearcut watersheds than on the selection and control watersheds (Table 4). The difference between the selection and control watersheds was not statistically significant.

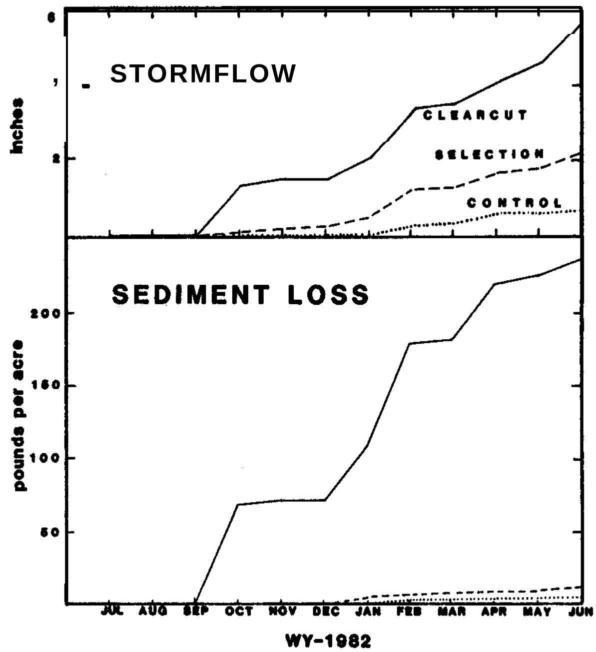

Figure 1. Accumulated monthly stormflows and sediment losses for the post-treatment water-year.

Table 4. Monthly discharge weighted sediment concentrations (ppm) by watershed and treatment for WY 1982.

	Clearcut			Selection			Control		
Month	1	5	9	2	4	8	3	6	7
July	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0
Sept	0	0	101	0	0	181	0	0	31
Oct	320	296	11	0	7	8	0	0	0
Nov	58	58	35	0	0	32	0	0	0
Dec	0	0	0	22	0	0	0	0	0
Jan	234	624	235	143	79	17	44	0	2
Feb	177	338	375	14	16	22	18	0	77
Mar	60	26	16	6	27	0	0	0	0
Apr	184	149	301	33	27	16	39	0	19
May	72	120	50	12	11	0	0	0	0
Jun	83	81	22	32	28	18	33	0	12
ANNUAL WEIGHTED AVERAGE	196	265	163	39	28	18	26	0	41
WEIGHTED AVG.BY TREATMENT		204 a			26 b			39 b	

During the pre-treatment year (WY-1981) the discharge-weighted mean sediment concentrations for the three control watershed5 was 79 ppm (Beasley **1982)**, about twice that of the post-treatment water year. This indicates that, even using discharge-weighted concentrations a5 a basis for comparing sediment losses, the results of watershed studies are weather dependent. Several large intense storms occurred when soils were saturated during the pre-treatment year but such storms were lacking during the post-treatment year.

The discharge-weighted concentrations for the **clearcut** watersheds were much lower than those reported elsewhere. Sediment concentration from a steep, erodible watershed receiving a similar **silvicultural** treatment in north Mississippi, was 2837 ppm (Beasley 1979). Moderately sloping **clearcut** and site prepared watersheds in east Texas yielded 2714 ppm (DeHaven et al. 1982). Discharge-weighted sediment concentrations from four clearcut, sheared, and windrowed watershed5 in the Piedmont of North Carolina averaged 2824 ppm (Douglass and Goodwin 1980). A significant factor that may account for the large differences in sediment losses per unit of stormflow between the **clearcut** watershed5 reported here and those described above is slope gradient. Slope increase5 the velocity of surface runoff which increases the sediment carrying power of the water (Hewlett and Nutter 1969).

Sediment concentration5 for the **clearcut** watershed5 reported here are less than those reported for uncut forests in other areas. Average annual sediment concentration for an **88** acre watershed with **loblolly** pine cover in north Mississippi was 780 ppm, most of which was attributed to channel degradation **(Ursic** 1975). Discharge-weighted sediment concentrations of major river basins in the South range from less than 300 ppm to more than 2,000 ppm, (Rainwater 1962). Maximum concentration5 are generally associated with high flows.

Fish production in warm southern streams suffers when suspended sediment concentration5 exceed 100 ppm for a sustained period (Buck **1956)**, but many species will tolerate very high levels for short period5 (Oschwald 1972).

CONCLUSIONS .

Clearcutting followed by intensive mechanical site preparation caused a statistically significant increase in storm discharge and sediment losses during the first post-treatment year. However, evaluating the biological significance of these measured losses in downstream water5 is **much more** difficult. In the Gulf Coastal Plain most stream channels and banks are comprised of highly erodible material which are readily detached and transported by streamflow. In many cases stream channel scouring alone account5 for higher concentrations of sediment than those measured in this study.

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AN OVERVIEW OF WATERSHED AND NUTRIENT CYCLING RESEARCH AT THE REYNOLDS HOMESTEAD RESEARCH CENTER[1/]

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Abstract.--A project designed to quantify the changes brought about by clearcut harvesting and site preparation has been established on the Virginia Piedmont. Four forested watersheds were selected for study in 1980. Three of the watersheds were commercially clearcut during the summer of 1981. The fourth watershed remained undisturbed and serves as a control. The clearcut watersheds were site prepared in July 1982. Three separate treatments: chop and burn; shear-disk (l-pass); and shear, rake-pile, disk (3-pass), representing three levels of site preparation intensity were applied. The site prepared watersheds will be planted to loblolly pine in March 1983. H-flumes and ceramic cup lysimeters were installed to monitor changes in streamflow and soil solution. Preliminary results indicate that prior to site preparation, nutrient levels in both soil solution and stream water were higher in the clearcut watersheds. Suspended sediment levels in stormflow from the clearcut watersheds were also higher. Post site preparation nutrient levels in soil solution were higher than levels in the control. Levels of NO_3-N in soil solution and stream water from both the clearcut and the site prepared watersheds were higher than NH_4-N. This indicates that nitrification may be an important process in disturbed ecosystems on the Piedmont.

INTRODUCTION

The importance of the southeastern United States as a timber producing region is expected to increase substantially in the next 20 years. It has been estimated that by the end of this century the southeast will produce roughly 50% of the total roundwood harvest of the U.S. (USDA Forest Service, 1973). However, the current stand quality and age of much of the commercial forest land in the region may not be adequate to meet future demands (Southern Forest Resource Analysis Committee, 1969). In addition, over 100,000 acres of potential pine forest land are lost each year because of inadequate regeneration following harvest or direct conversion of forest land to other uses (Knight, 1977).

In order to meet the increasing demands on the forest resources of the southeast, intensive forest management practices will have to be applied to a larger acreage. On the Piedmont, this will probably include the conversion of mixed pine-hardwood stands to short rotation pine plantations (Switzer and Nelson, 1973).

Reported declines in productivity of intensively managed second rotation plantations in other parts of the world (Whyte, 1973; Will and Ballard, 1976) have generated concern about similar declines in productivity in the southeast. Agricultural experiences in the past have demonstrated that Piedmont sites are particularly susceptable to productivity declines under intensive management.

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A number of recent symposia have been held on the effects of intensive management on productivity (Tippin, 1978; Leaf, 1979 and Mann, 1980). Most of the deleterious effects of intensive forest management are associated with reductions in soil nutrient reserves or with the ability of the system to effectively cycle nutrients (Pritchett and Wells, 1978; Wells and Jorgensen, 1979; Pritchett, 1980) and with harm to the physical properties of the soil (Campbell, 1973; Haines et al., 1975; Nutter and Douglass, 1978; Greacen and Sands, 1980; Pritchett, 1980).

Mechanical site preparation is used extensively in the southeast to eliminate logging slash, reduce competing vegetation and manipulate the site in an attempt to optimize survival and early height growth of planted seedlings (Duzan, 1980). There is no one site preparation prescription that is applicable to all areas. To improve their effectiveness and cost efficiency, site preparation prescriptions must be site specific. Social and environmental factors must also be considered (Balmer et al., 1976).

Excessive soil disturbance during site preparation is a major factor influencing productivity declines (Pritchett, 1981). These same disturbances may also substantially increase sediment concentrations in stream water thus degrading water quality (Stone et al., 1978). The Federal Water Pollution Control Act (PL 92-500) has classified harvesting and site preparation activities as non-point sources of pollution. As such, it is required by law to control discharges from forest land using "best management practices" (Rey, 1980).

In light of these two factors, several research efforts in the southeast are actively investigating the effects of harvesting and site preparation. The small watershed technique has been used at Coweeta Hydrologic Laboratory since the early thirties to evaluate the effects of management practices on the timing, quantity and quality of streamflow from forested catchments (Douglass and Swift, 1977). Streamflow changes due to cutting and vegetation changes have been quantified and predictive equations developed for forested catchments subject to disturbance (Douglass and Swift, 1977). The current research effort at Coweeta emphasizes the effects of forest practices on stream water quality and nutrient cycling (Douglass and Swift, 1977).

The U.S. Forest Service also maintains a hydrologic lab on the Coastal Plain at Oxford, Mississippi. The effects of intensive forest management practices on the upper Coastal Plain are being evaluated. It has been found that practices such as chopping, shearing, windrowing and bedding increase sediment losses. However, these losses tend to diminish after the first year (Beasley, 1979). Sediments were also shown to be an important factor in the export of nitrogen from forested watersheds. Sediment-phase losses were found to equal aqueous-phase (dissolved) losses (Schrieber et al., 1980).

A cooperative project between the University of Florida, the U.S. Forest Service and forest industry was installed to evaluate the effects of intensive management on the slash pine (Pinus elliotti) ecosystem of the lower Coastal Plain (Swindel et al., 1981). The Intensive Management Practices Assessment Center (IMPAC) has used paired watersheds to demonstrate increased water yield following harvesting and site preparation. Water quality changes, although variable, tend to increase with the level of site disturbance (Swindel et al., 1981).

The effects of clearcutting and regenerating a southern Piedmont forest have been studied recently by Hewlett (1979). Results from this study indicate an increase in water yield following clearcutting and site preparation. However, large increases in nutrient export and sediment load in stream water were not reported.

A site preparation study has recently been established by the Southern Regional Forest Center. This is a study designed to evaluate the effects of intensive management practices on loblolly pine (Pinus taeda) growth.[3] Sites have been selected on both the Piedmont and the Coastal Plain in an effort to provide basic information on the effects of intensive management on soil properties and nutrient cycling throughout the range of loblolly pine.

Watershed research at the Reynolds Homestead Research Center is a cooperative project between the Department of Forestry at Virginia Tech, Champion International Corporation and the U.S. Forest Service. The objective of the project is to quantify the changes associated with clearcut harvesting and site preparation on the Virginia Piedmont. Specific emphasis is placed on 1) seedling survival and growth, 2) nutrient dynamics, 3) soil erosion and compaction, 4) stream water quality and 5) organic matter transformations. This report presents an overview of the study site, treatments, methods, and preliminary results on the effects of harvesting and site preparation on stormflow and soil solution nutrient concentrations.

MATERIALS AND METHODS

The Reynolds Homestead Research Center is located on the Piedmont in Patrick County, Virginia (fig. 1). The land use history of the Reynolds Homestead is typical of much of the southern Piedmont. Abusive agricultural practices associated with the production of tobacco caused severe erosion that was accompanied by substantial declines in productivity. Much of the eroded agricultural

3/ Larry Morris, Personal communication.

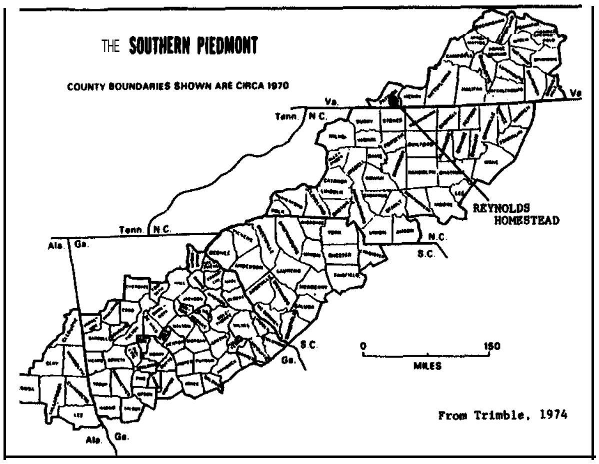

Figure 1.--Location of the Reynolds Homestead in relation to the Southern Piedmont.

land was eventually abandoned and has since grown into low quality mixed stands of pine and hardwoods.

In the summer of 1980, four small forested watersheds drained by ephemeral streams were selected for study. Watersheds 1 and 2 are approximately 4 acres each, watershed 3 is approximately 8 acres and watershed 4 is approximately 9 acres.

Both the overstory and understory vegetation in each watershed were characterized. Overstory trees were measured using variable radius plots with a sampling intensity of one point per acre. The understory vegetation was sampled using the line transect method.

The four watersheds were equipped with l-foot H flumes to measure runoff (Douglass and Swift, 1977). A plywood trough 8 feet long, 27 inches wide and 19 inches deep served as a sediment trap and approach section to the flume. Stage height was measured by a strip chart recorder at a stilling well connected to the flume by rubber tubing. The volume of flow was calculated for each runoff event. A 2-foot diameter Coshocton wheel mounted below each flume collected approximately 0.5% of the flow. The Coshocton wheel was connected to a plastic barrel where the runoff was stored prior to sampling. When a large volume of flow was anticipated, a 10:1 sample splitter was placed between the Coshocton wheel and the plastic barrels which reduced the stored sample to about 0.05% of the total flow.

After each event, the stormflow diverted to the plastic barrel was sampled. Sediment was determined gravimetrically after filtration through 0.42 micron fiberglass filter paper. The samples were analyzed for K, Ca, Mg, conductivity, and pH using the standard methods employed in the Forest Soils/Tree Nutrition lab at Virginia Tech. NH_4-N, NO_3-N and PO_4-P were determined at the Virginia Tech Water Quality Lab using the methods described by Smolen et al. (1978). Total N was determined by Kjeldahl digestion.

Following a one year calibration period, three of the four watersheds were commercially clearcut. Conventional chainsaw felling and yarding with rubber tired skidders was used to harvest the timber. The harvesting operation was completed in October 1981.

In late fall, 1981, soil solution lysimeters were installed at two depths, 6 and 12 inches, at ten random locations in each watershed. Soil solution samples were collected biweekly. NH_4-N, NO_3-N, PO_4-P, K, Ca, Mg, pH and conductivity were determined on the soil solution samples using the same analytic techniques as employed with the stream water samples. Soil moisture and temperature were also determined at biweekly intervals.

Three separate site preparation prescriptions, representing three levels of intensity, were applied to the clearcut watersheds in July, 1982. The intensity of each prescription was classified on the basis of the amount of disturbance to the forest floor and residual biomass.

Watershed 1, the uncut control, was not site prepared. It remains an undisturbed control.

Watershed 2 was subjected to the least intensive treatment, chop and burn. A Marden double drum chopper weighing approximately 42,000 lbs was pulled over the area by a Caterpillar D-7G tractor. The residual standing trees were knocked down and the smaller diameter material cut into pieces. Two months after chopping, in September, 1982, the area was broadcast burned. The end result of this treatment was that the forest floor remained essentially intact and, except for elements volatized by the fire (primarily N), the nutrients present in the slash remained on the site distributed over the area in the ash. These nutrients were readily available and could rapidly move in the nutrient cycle.

An intermediate level of site preparation intensity was applied to Watershed 3. The site preparation prescription consisted of the shear-disk, l-pass operation. In a single pass over the site, the residual material was sheared and the forest floor was turned into the mineral soil. The results of this treatment differ from those of the chop and burn in that 1) the forest floor is disturbed and 2) although all the nutrients in the slash remain on the site, they are tied up in the residual material and are released to the active nutrient cycle at a much slower rate.

The most intensive treatment was applied to watershed 4. This area was sheared, piled and disked in three separate passes with a Caterpillar D-7G. Windrows were located either on the contour or in erosion ditches and were burned two months after site preparation. In this treatment, the nutrients contained in the slash were localized at the sites of the burned windrows. They are, for the most part, not available to the majority of trees in the next rotation.

Following site preparation, sediment traps were constructed in each of the prepared watersheds to measure downslope soil movement. The sediment traps will be used to validate soil erosion losses from each site as predicted by the Universal Soil Loss Equation (Dissmeyer and Foster, 1980).

Each of the site prepared watersheds will be planted with loblolly pine in the spring of 1983. Survival and growth will be measured periodically. Growth data will be correlated with results from the nutrient dynamics portion of the study to evaluate the impact of the three levels of site preparation on both short-and long-term site productivity.

RESULTS AND DISCUSSION

Site Characterization

The principal soil mapping units in the study watersheds were:

Watershed 1	Cecil Fine Sandy Loam, Cecil Clay Loam, Appling Fine Sandy Loam
Watershed 2	Hayesville Cobbly Loam, Hayesville Fine Sandy Loam, Cecil Fine Sandy Loam
Watershed 3	Cecil Fine Sandy Loam
Watershed 4	Cecil Clay Loam, Cecil Fine Sandy Loam, Appling Fine Sandy Loam

Selected soil physical and chemical properties are presented in Table 1.

A summary stand table of the overstory vegetation is presented in Table 2. Site index data is presented in Table 3, and the understory vegetation characterization data is presented in Table 4.

The soils of the four watersheds are derived from similar parent material and are quite similar. The major differences are in the depth of the A horizon, which is due to differential erosion. The vegetation on the watersheds was quite different. Pine dominated the overstory in watershed 2. The species composition in watersheds 1 and 4 was more evenly distributed between pine and hardwoods. Watershed 3 was dominated by hardwoods. Differences in vegetation and topsoil depth can be traced to the past land use pattern of the individual watersheds and contributes to the inherent watershed differences.

Clearcutting Effects

The drought that occurred during 1980 and 1981 severely affected runoff from the gauged watersheds. The relative scarcity of streamflow data for the first half of 1981 (Table 5) can be attributed to the drought.

Overall sediment concentrations in stormflow from the clearcut watersheds are greater than concentrations in the undisturbed watersheds. Most of the sediment in streamwater from the clearcut watersheds is associated with the construction of roads and landings in the upper parts of the drainage basin. Very little soil disturbance was observed in other areas of the clearcut.

Nutrient concentrations, although variable, were generally greater in stormflow originating on

Table 1.--Selected soil properties for research watersheds at the Reynolds Homestead Research Center, Patrick County, Virginia.

Watershed	Site Preparation Prescription To Be Applied	Soil Horizon	Depth	BD	OM	pH	K	Ca	Mg
			(cm)	(g/cc)	(%)		- - - (ppm)[1]	- - -	
1	Control	A	21.8	1.10	2.6	4.3	11.2	8.2	8.2
		B	100	1.46	0.2	4.9	10.7	12.3	3.3
2	Chop and Burn	A	13.9	1.04	2.2	4.3	5.6	3.0	0.9
		B	100	1.46	0.6	4.9	7.2	4.6	7.0
3	Shear-disk (1 pass)	A	13.9	0.97	3.7	4.5	10.0	6.8	3.4
		B	100	1.36	0.9	5.0	6.9	9.2	6.6
4	Shear, rake-pile, disk (3 pass)	A	12.9	1.01	2.6	4.8	6.8	4.4	2.0
		B	100	1.39	0.7	5.2	9.9	19.0	11.5

[1] Double acid (0.05N HCl + 0.025 N H_2SO_4) extraction.

Table 2.--Summary stand table of research watersheds at the Reynolds Homestead Research Center, Patrick County, Virginia.

Watershed	Site Preparation Prescription to be Applied	Va. Pine	Other[1] S.W.	Oak[2]	Tulip Poplar	Other[3] H.W.	Total S.W.	Total H.W.	Total
		(trees/acre)							
1	Control	661	1	18	86	368	662	472	1,134
2	Chop and burn	400	34	5	16	479	435	500	935
3	Shear-disk (1 pass)	88	6	95	19	767	94	881	975
4	Shear, rake-pile, disk (3 pass)	320	4	4	87	455	324	546	870

1/ Species include white pine, Table-Mountain pine, Pitch pine and Eastern red cedar.

2/ Species include white oak, northern red oak, chestnut oak and scarlet oak

3/ Species include black gum, sourwood, red maple, beech, green ash, black cherry, dogwood and black locust.

the clearcut watersheds (Table 5). Both NH_4-N and NO_3-N concentrations are greater in stream water from the clearcut watersheds. It is interesting to note that NO -N levels in streamwater from both the clearcut ana control watersheds are greater than NH_4-N levels.

The relationship between streamflow PO_4-P concentrations in the clearcut and control watersheds varies from month to month, although, on the average, higher concentrations do occur in streamflow from the clearcut watersheds. However, levels from both areas are quite low.

K concentrations are higher in streamflow from the clearcut watersheds. Similar results were observed for Ca and Mg concentrations.

The effect of clearcut harvesting on soil solution nutrient concentrations can be seen in Table 6. NH_4-N and NO_3-N concentrations in samples from the clearcut watersheds were significantly greater than the control. In addition, NO_3-N levels tend to be higher than NH_4-N in the clearcut watersheds. The reverse occurs in the control watershed. This indicates that nitrification is a significant factor in the disturbed watersheds, but not in the control. Similar results have been observed by Likens, et al. (1970).

PO_4-P concentrations in soil solution from the clearcut watersheds were significantly greater than the PO_4-P concentrations in soil solution from the control watershed. However, as with the stresmwater samples, PO_4-P concentrations from both

Table 3.--Site indices for selected species on research watersheds at the Reynolds Homestead Research Center, Patrick County, Virginia.

Watershed	Site Preparation Prescription to be Applied	Site Index[1] Virginia Pine	White Pine	Tulip Poplar
		ft		
1	Control	70	82	94
2	Chop and burn	66	--	--
3	Shear-disk (1 pass)	67	65	93
4	Shear, rake-pile, disk (3 pass)	69	70	91

1/ Site index base age 50 years.

Table 4.--Understory vegetation characterization of research watersheds at the Reynolds Homestead Research Center, Patrick County, Virginia.

Watershed	Site Preparation Prescription to be Applied	Species						
		Soil	Grass	Forb	Vine	Shrub	H.W.	Pine
		------ (% dominance)[1] ------						
1	Control	0.0	0.3	2.2	20.2	16.4	0.9	24.9
2	Chop and burn	1.5	0.6	11.0	4.4	17.8	36.9	1.8
3	Shear-disk (1 pass)	2.2	0.0	2.7	7.8	17.8	34.3	0.6
4	Shear, rake-pile, disk (3 pass)	0.0	0.1	2.9	9.2	10.6	0.8	17.3

1/ Dominance is calculated as:

$$\text{dominance} = \frac{\text{total intercept length of species A}}{\text{total transect length}} \times 100$$

Table 5.--Monthly and cummulative averages of selected stream water properties from research watersheds prior to site preparation.

	Date	Sediment Control	Sediment C.C.[1]	NH_4-N Control	NH_4-N C.C.	NO_3-N Control	NO_3-N C.C.	PO_4-P Control	PO_4-P C.C.	K Control	K C.C.
		(g/ml)		(ppm)							
1981	Feb	0.031	2.334	5.60	1.21	1.44	0.04	0.010	0.011	2.42	••
	Mar	*	*	*	*	*	*	*	*	*	*
	Apr	*	*	*	*	*	*	*	*	*	*
	May	*	*	*	*	*	*	*	*	*	*
	June	*	*	*	*	*	*	*	*	*	*
	July	0.038	*	0.40	*	0.00	*	0.000	*	2.56	*
	Aug	*	*	*	*	*	*	*	*	*	*
	Sept	0.030	1.473	4.34	1.47	6.38	2.73	0.019	0.013	0.51	3.69
	Oct	0.035	0.148	0.63	1.15	0.39	2.48	0.014	0.009	2.40	3.74
	Nov	*	*	*	*	*	*	*	*	*	*
	Dec	0.006	0.177	0.61	0.63	0.75	4.45	0.010	0.034	2.95	13.20
1982	Jan	0.016	0.146	0.55	0.62	0.41	0.86	0.001	0.015	1.39	1.88
	Feb	0.012	0.070	0.11	0.24	0.30	0.81	0.009	0.006	1.09	1.49
	Mar	0.011	0.086	0.11	0.00	0.17	0.00	0.000	0.000	0.35	5.28
	Apr	0.010	0.065	0.14	0.03	0.31	4.29	0.000	0.002	1.42	3.01
	May	0.020	0.670	2.76	0.33	3.12	1.94	0.006	0.021	2.88	4.95
	June	0.047	0.327	0.55	9.66	0.68	0.85	0.043	0.299	5.10	4.82
	July			0.04	1.01	1.20	1.02	0.003	0.021	4.20	7.67
	Cumulative Average	0.023	0.351	0.92	1.63	1.25	1.95	0.01	0.04	2.26	5.05

1/ Clear cut.
* No run off event occurred during this month.

Table 6.--Mean soil solution values for research watersheds at the Reynolds Homestead Research Center, Patric County, Virginia, as affected by clearcut harvesting.

Treatment	NH_4-N	NO_3-N	PO_4-P	K	Ca	Mg	Conductivity	pH
	(ppm)						(mmhos)	
Control	0.08a[1/]	0.01a	0.008a	1.96a	2.09a	0.92a	25.9a	5.3a
Clearcut	0.22b	0.60b	0.016a	2.64b	3.19b	1.30b	37.5b	5.3a

1/ Values in a column with the same letter are not significantly different (α = 0.05).

the clearcut and the control watersheds are quite low. This is probably due to the low level of water soluble P found in most Piedmont soils.

Conductivity and cation concentrations in soil solution were also significantly higher in the clearcut watersheds (Table 6). These higher levels were probably responsible for the increased levels of nutrients in the stream water.

Effects of Site Preparation

Unfortunately, no runoff events have occurred since site preparation. Thus, it was not possible to determine the effects of site preparation on any stream water parameters. Soil solution data for the first three months since site preparation is presented in Table 7. Although there was a trend towards higher levels of NH_4-N in the site prepared watersheds, there were no significant differences. A similar trend with NO_3-N values did indicate a significantly higher concentration of NO_3-N in the soil solution of the most intensive treatment. In the two more intensive treatments, the shear, pile, disk and the shear-disk, NO_3-N levels were greater than NH_4-N levels. In the chop and burn and control watersheds the reverse occurred. This seems to indicate that nitrification was an important process in the more intensive treatments, but not in the undisturbed and minimally disturbed areas.

PO_4-P values were not significantly different among any of the site preparation treatments or the control. The low level of readily available P in Piedmont soils was again demonstrated by the low concentrations of P in soil solution.

Conductivity and cation values in soil solution tended to increase with increasing intensity of site preparation. K levels in each of the site prepared watersheds were greater than the control. Ca, Mg and conductivity values paralleled those of K, but only the most intensive treatment was actually significantly greater.

CONCLUSIONS

Preliminary results from this study showed that clearcutting and site preparation increased levels of nutrients in soil solution. This may be due to a combination of increased organic matter mineralization and a decrease in nutrient uptake by vegetation.

Clearcutting was also found to increase the nutrient concentration and sediment load of stormflow. The increased level of nutrients in

Table 7.--Mean soil solution values for research watersheds at the Reynolds Homestead Research Center, Patrick County, Virginia, as affected by site preparation.

Site Preparation Prescription	NH_4-N	NO_3-N	PO_4-P	K	Ca	Mg	Conductivity	pH
	(ppm)						(mmhos)	
Control	0.57a[1/]	0.18a	0.010a	2.59a	1.31a	1.36a	27.5a	5.26ab
Chop and burn	0.66a	0.32a	0.005a	5.00b	2.33a	1.37a	58.5a	5.25a
Shear-disk (1 pass)	0.95a	1.78a	0.012a	5.34b	3.14a	1.77a	67.9a	5.57ba
Shear, rake-pile disk (3 pass)	0.86a	4.75b	0.012a	5.561,	7.92b	2.84b	104.8b	5.66c

1/ Values in a column with the same letter are not significantly different (α = 0.05).

stream water draining from the clearcut watersheds is probably related to the higher levels of nutrients in soil solution in the clearcut areas. Increased sediment loads in streamflow from the clearcut watersheds were probably associated with the construction of roads and landings during the harvesting operation. The higher levels of both sediments and nutrients in streamflow originating on the clearcut watersheds may detrimentally affect downstream water quality.

NO -N levels were greater than NH_4-N levels in the aisturbed watersheds. Nitrification appeared to be an improtant process in the disturbed areas. This can have important consequences because of the great mobility of the nitrate anion. NO_3-N leached from the active rooting zone is no longer available to the tree crop. There are also potential health hazards associated with high nitrate levels in drinking water.

Since forestry operations are classified as non-point sources of pollution, these potential impacts of intensive management should be of concern to forest managers, particularly since they may also be related to potential declines in long term site productivity.

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NUTRIENT DISTRIBUTIONS IN RUNOFF FROM OUACHITA MOUNTAIN WATERSHEDS 1/

Edwin R. Lawson and Leslie H. Hileman 2/

Abstract.--Nutrients in runoff from four watersheds in the Ouachita Mountains of Arkansas were monitored. One watershed received a final shelterwood harvest and another was burned and planted with shortleaf pine. Nutrients included: P, K, Ca, Fe, Na, NH_3-N, Mg, Mn, NO_3, and HCO_3. Turbidity, pH, and specific conductance were also evaluated. Treatments did not generally alter nutrient levels in runoff.

INTRODUCTION

Forested wateraheds are generally recognized as the primary source of high quality water in the United States (Corbett et al. 1978; Douglass 1974; Stone 1977) and that altering the forest cover influences the amount and quality of water provided from these areas. Forest cover is usually changed through a variety of silvicultural practices applied to achieve certain forest management objectives. A considerable amount of literature is available on the effects of such practice5 on water quality, but research result5 vary greatly depending on such factors as soil characteristics, vegetation, climate and degree of disturbance (Brozka et al. 1981; Douglass 1974).

There is currently very little similar information available for the upland areas of the Ozark-Ouachita Highlands. Losses of sediment and nutrients from the rather shallow soils characteristic of the region may be critical. In addition, excessive downstream loading of sediment and nutrients may be detrimentalto aquatic habitat.

STUDY AREAS

The four watersheds are on the Alum Creek Experimental Forest in central Arkansas. Three of the watersheds (WS-1, WS-2, and WS-3) are 1.63, 1.28, 1.44 acres in size, respectively. They are adjacently located at the headwaters of Watershed 4 (WS-4), which is 32.5 acres in size. Hydrologic characteristics of the three smaller watershed5 in an undisturbed condition were reported by Rogerson (1971). Elevations within WS-4 range from 1120 feet at the gaging site to about 1400 feet at the headwaters. Average slopes are about 15 percent for the smaller watersheds and 20 percent for WS-4.

Watershed soils are in the Carnasaw-Townley-Pirum association (Haley 1979). These soils are well drained, undulating to steep, shallow to moderately deep stony loam soils on hills, mountains, ridges, and colluvial areas. The Carnasaw and Townley series are characterized by a thin layer of loam material and underlying-clayey material weathered from shale. These series are classed as clayey, mixed, thermic typic Hapludults (U.S. Department of Agriculture 1975). Pirum soils are classed a5 fine-loamy, siliceous, thermic typic Hapludults. All of these soil series are underlain by tilted and fractured shale, sandstone, or quartzite.

Annual precipitation in the study area averaged 52.5 inches between 1961 and 1969 (Rogerson 1971). Precipitation at the Alum Fork climatological station 10 miles east of the catchments averaged 53.26 inches over a 30-year period (U.S. Department of Commerce 1981). Average long-term monthly precipitation range5 from about 3.30 inches in October to 5.83 inches in May. Almost all precipitation is in the form of rain, but light snow falls a few time5 each winter with an occasional heavy snowstorm. Annual temperature averages 62.1°F, and the January and July means are 42.3°F and 81.6°F, respectively. The average

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growing season is 214 days and extends from March 30 to October 31.

Vegetation WS-1 and the untreated part of WS-4 consists primarily of an overstory 70- to 80-year-old shortleaf pine (Pinus echinata Mill.) with an occasional dominant hardwood. Pine basal area averages about 100 square feet per acre. In 1970, the understory on the smaller basins contained about 34 square feet of basal area of hardwoods, consisting primarily of a mixture of white oak (Quercus alba L.), northern red oak (Q. rubra L.), black oak (Q. velutina Lam.), blackjack oak (Q. marilandica Muenchh.), dogwood (Cornus florida L.), red maple (Acer rubrum L.), hickories (Carya spp.), and black gum (Nyssa sylvatica Marsh.). A few other tree, shrub, and herbaceous species occur less frequently. Most of the hardwoods are less than 30 feet in height, and some are less than 15 feet.

Vegetation on WS-2 and WS-3 was altered during silvicultural treatments in 1970 and again in 1977. A shelterwood cut was made in the pine overstory on WS-2 in 1970, leaving about 60 square feet of pine basal area. All hardwoods an inch and larger at the root collar were injected with herbicides. These deadened hardwoods were severed in 1971. The watershed was sprayed three times during the next 7 years to control competing vegetation and measure herbicide concentrations in runoff (Lawson 1976). Natural shortleaf pine regeneration developed rapidly under the shelterwood overstory averaging about 1500 seedlings and small saplings per acre by 1977. The remaining pine overstory was then harvested. Herbaceous cover consisted primarily of native grasses and a few shrubs of varying density, depending on' pine stocking. The pine saplings were precommercially thinned in 1981 to about an 8-by-10 foot spacing.

In 1970 all merchantable timber on WS-3 was harvested and the hardwoods deadened in the same manner as on WS-2. The clearcut watershed was also sprayed with herbicide three times. Grass vegetation developed within two growing seasons on the area and formed a dense cover which was maintained to observe its effects on soil moisture levels and water yield. In December 1976, the watershed was burned to remove the rough grass and planted with 1-0 shortleaf pine seedlings at 8-by-10 foot spacing or about 544 trees per acre. Spots where first year survival was low were replanted the next dormant season. Grass cover developed during the first growing season following the burn. No other treatments were imposed on WS-3.

STUDY METHODS

Field Measurements

Runoff from watersheds 1, 2, and 3 was measured with 3-foot H-type flumes, and WS-4 with a 4.5-foot H-flume, all equipped with FW-1 water level recorders. One-liter water samples were automatically collected as streamflow reached stage heights of 0.05, 0.10, 0.20, 0.30, 0.50, 0.75 and 1.00 foot in the 3-foot flumes and at additional heights of 1.50, 2.00 and 3.00 feet in the 4.5-foot flume. The technique developed by Sartz and Curtis (1967) allows sampling during the rising stages only and prevents purging after collection. Samples were picked up as soon as possible after each runoff-producing storm and placed in cold storage until examination.

Laboratory Analyses

All laboratory analyses and measurements were performed by the University of Arkansas Soil Testing Laboratory, using standard methods (U.S. Environmental Protection Agency 1976; American Public Health Association 1971). Analyses of all individual elements were not made throughout the entire study period due to lack of available analytical equipment, or insufficient samples. Analyses were made on unfiltered samples.

The following determinations were made for each sample, except where sample quantities were insufficient: hydrogen ion concentration (pH), iron (Fe), manganese (Mn), total phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), ammonia nitrogen (NH_3-N), nitrate (NO_3), carbonate (CO_3), bicarbonate (HCO_3), specific conductance, and turbidity. All data are given in milligrams per liter (mg/l) except pH, specific conductance and turbidity, which are pH units, µmhos/cm at 25°C, and nephelometric turbidity units (NTU), respectively.

Statistical Analyses

The water sample data was summarized in two groups relating to time periods: the first period extending from 1973 to early 1977, and the second period from 1977 into 1981. These groups were analyzed separately because they represented the break point between the 1970 post-treatment data and that following the 1977 treatments being evaluated in this study. Also, there were laboratory analyses in the second group that could not be performed earlier due to lack of equipment.

In the 1973-1977 period, the number of samples for most nutrients ranged from 127 on WS-1 to 246 on WS-4, except for Ca and NH_3-N. The number on WS-1 and WS-4 for Ca ranged from 73 to 184 and for NH_3-N, 14 to 57. The number per watershed in the 1977-1981 period generally ranged from 63 on WS-1 to 193 on WS-4, with slightly lower ranges for HC03 and NO_3.

The experimental design called for a split-plot analysis, but an alternative analysis was used because of unbalanced data. Thus, statistical tests should be regarded as approximate. The alternative statistical analyses were performed using the General Linear Models Procedure provided by Statistical Analysis System Institute, Inc. (1979). Each of the measured parameters were considered to be the dependent variable in the analyses. The model included watershed, month that samples were collected and the interaction of watershed and month. The analysis of variance test (TYPE IV) provided "F" values and significance probability for the model and its sources; watershed, month, and watershed x month interaction. Only probabilities of 0.01 or less were considered significant in all tests. Differences between means were tested using a least significant difference procedure for unequal replication (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Several factors affecting interpretation of results should be kept in mind.. First, due to precipitation patterns there may be little or no runoff from these ephemeral streams in a given month compared with the same month in another year. A similar variation among seasons and years is characteristic of runoff patterns. Second, there are some inherent differences in runoff response among watersheds that affect sampling frequency. Watershed 4 has the greatest volume of runoff and has the highest runoff-precipitation ratio. Data from WS-4 are more representative of larger basins in the Ouachita Mountains than data from the other watersheds. On WS-2 and WS-3, previous treatments have also influenced runoff responses. Third, antecedent soil moisture affects the amount of runoff and therefore the amount of leaching that takes place in response to a storm. Thus, previous leaching may cause changes in nutrient concentrations or other chemical, and physical properties of storm runoff. Nutrient release is known to be affected by soil moisture and soil temperatures (Pritchett and Wells 1978).

Most concentrations of nutrients found in runoff were relatively low, especially Fe, Mn, and P during the 1973-1977 period (Table 1) and these nutrients plus Mg in the 1977-1981 period (Table 2). The concentrations of P, Mn and Mg were not

Table 1.--Nutrient concentrations in runoff from the Alum Creek watersheds during the 1973-1977 period.

Nutrient	WS-1	WS-2	WS-3	WS-4
	mg/l			
Fe	0.23a	0.19a	0.20a	0.17a *
Mn	0.04a	0.03a	0.04a	0.04a
P	0.19a	0.17a	0.18a	0.16a
K	0.81b	1.75d	1.29c	0.55a
Ca	1.72a	1.92a	1.64a	1.14a
Na	0.53a	1.17c	0.90b	0.82b
NH_3-N	2.02c	1.20b	1.32b	0.61a

* Means followed by the same letter in a line are not significantly different at the .01 level.

Table 2.--Nutrient concentrations in runoff from the Alum Creek watersheds during the 1977-1981 period.

Nutrient	WS-1	WS-2	WS-3	WS-4
	mg/l			
Fe	0.09b	0.12b	0.21a	0.11b *
Mn	0.06a	0.07a	0.08a	0.06a
P	0.09a	0.14a	0.12a	0.07a
K	1.08b	1.49c	0.96b	0.54a
Ca	1.54c	1.75c	1.01b	0.56a
Mg	0.04a	0.05a	0.05a	0.05a
Na	0.58a	0.89a	0.79a	0.77a
HCO_3	12.03a	13.71a	10.96a	9.56a
NH_3-N	1.02c	0.74b	0.62b	0.42a
NO3	2.31a	2.89a	2.82a	2.44a

* 'Means followed by the same letter in a line are not significantly different at the .01 level.

significantly different among the watersheds or months. However, Mn levels from WS-2 and WS-3 more than doubled those from WS-1 and WS-4 during 1977 the first year after treatment. Only small differences among all watersheds occurred in other years. Phosphorus movement was not expected to be influenced by the treatments since vegetative changes usually increase solution P only slightly (Pritchett and Wells 1978). The levels of Fe in the early period ranged from 0.17 to 0.23 mg/l and there were no significant differences among the four watersheds. In the 1977-1981 period, the level of Fe from the burned watershed (WS-3) was significantly higher than the concentrations from the other watersheds. Concentrations of Fe from WS-3 were highest in 1977 and 1978, reaching about 0.4 mg/l (fig. 1). The causes of the increased levels of Fe are not known. Fe concentrations are strongly associated with month or season of the year (fig. 2). The highest levels occurred in April with a small peak in early fall.

Concentrations of Ca in runoff varied significantly among the four watersheds in the 1977-1981 period, and K followed the same trend in both periods. Levels of both nutrients were highest in WS-2 and lowest in WS-4 runoff. Lower concentrations of these and several other nutrients in runoff from WS-4 may be due to its much higher flow volume relative to precipitation. Ca and K showed significant seasonal trends during both periods, with K also showing an interaction between watershed and month. The interaction is evidenced by inconsistent ranking of watersheds over time in Figure 3. The three smaller watersheds had higher concentrations than WS-4. Data from the 1973-1977 period showed similar trends. Calcium showed the same trend in the 1977-1981 period, but was generally more variable. Burning on WS-3 aid not result in increased concentrations of either nutrient, although some increase is normally expected (Pritchett and Wells 1978). There was no runoff from WS-3 for nearly two months after the burn, which would allow these cations to be leached into the soil and absorbed before interflow occurred.

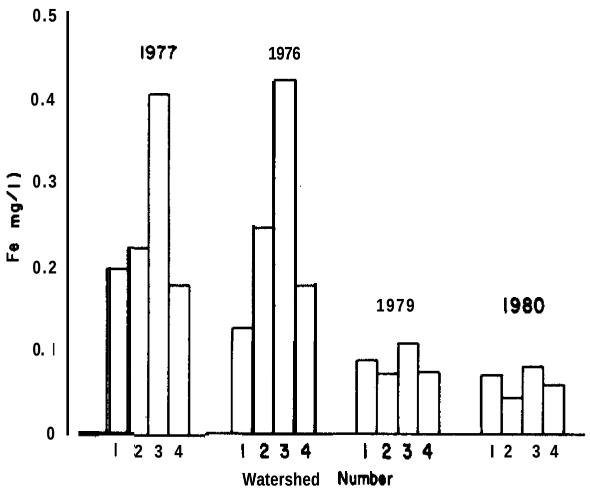

Figure 1.--Average concentrations of Fe in runoff by watershed and year.

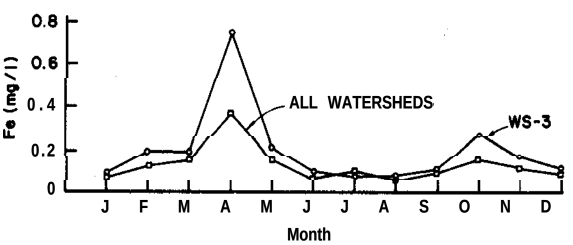

Figure 2.--Average monthly concentrations in Fe in runoff on WS-3 and all watersheds during the 1977-1981 period.

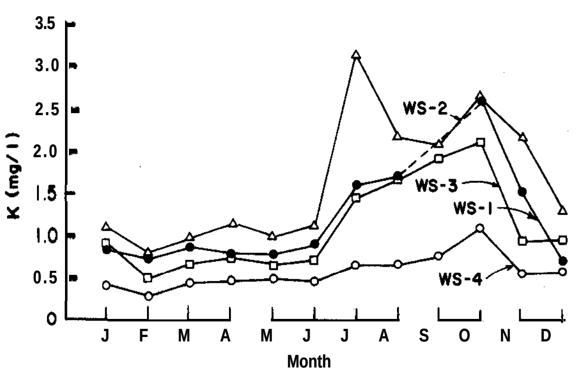

Figure 3.--Average concentrations of K in runoff by watershed during the 1977-1981 period.

Ammonia nitrogen (NH_3-N) in runoff varied significantly among the watersheds in both periods (Tables 1 and 2), with WS-1 having the highest and WS-4 the lowest levels. Higher levels of NH_3-N from WS-1 were very consistent throughout the study period. Differences in levels of NH_3-N between the two periods may be due to more accurate analytical techniques and a much greater number of samples in the 1977-1981 period. A significant difference in NH_3-N levels occurred among months in the 1977-1981 period, with WS-1 showing the highest levels (fig. 4). Causes of the peaks in March and November on WS-1 and. November on WS-2 cannot be explained, but they are based on 7 to 10 samples collected in 3 years. General trends indicate higher NH_3-N levels from late spring to early fall.

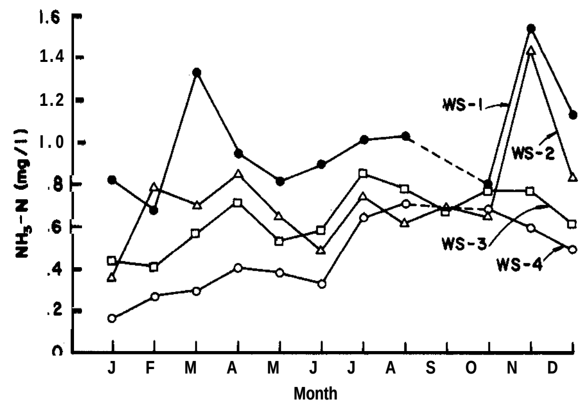

Figure 4.--Average concentrations of NH_3-N in runoff by watershed during the 1977-1981 period.

Nitrate (NO_3) levels ranged from 2.3 to 2.9 mg/l and there were no significant differences among the watersheds (Table 2), although runoff from the two treated watersheds had the highest concentrations.

Concentrations of Na in runoff were highest from WS-2 and lowest from WS-1 in both periods, but only significantly different in the early period. The generally low levels of Na found in runoff are expected since soils in the area are low in this nutrient. Reasons for the differences in Na levels among watersheds are not known, but the higher levels on WS-2 and WS-3 may be reflecting responses from vegetative changes made in the first cutting treatments. In the early period, Na concentrations were significantly related to months, but did not reflect seasonal changes.

Bicarbonate (HCO_3) concentrations ranged from 9.6 to 13.7 mg/l, with no significant differences among the watersheds (Table 2). Levels of HCO_3 were significantly associated with month, but the data showed no seasonal trends. The HC03 levels found in this study are very close to those reported from streamflow in Colorado (Lewis and Grant 1979). A large number of water samples were also analyzed for carbonate (CO_3), but it was rarely detected.

A specific conductance of 20.0 µmhos/cm in runoff samples from WS-4 was significantly lower than the other watersheds (Table 3). Samples from the **clearcut** watershed (WS-3) also had significantly lower conductance than WS-1 and WS-2. A seasonal trend is apparent from the significantly different monthly averages, with the highest levels occurring in late summer and fall (fig. 5). The average for July was the lowest for any month on all watersheds except WS-3. Data for July was only collected for 1978 and 1979 due to lack of runoff in other years, and. may not represent normal trends. Average conductance levels found in runoff from these watersheds are relatively low, indicating small amounts of dissolved minerals.

Table 3.--Levels of pH, specific conductance and turbidity in runoff during the 1977-1981 period.

Parameter	WS-1	WS-2	WS-3	WS-4
pH	4.87a	5.42c	5.13b	5.08b *
Cond. (µmhos/cm)	27.5c	28.9c	23.413	20.0a
Turbidity (NTU)	10.8a	18.1a	32.4a	10.0a

* Means followed by the same letter in a line are not significantly different at the .01 level.

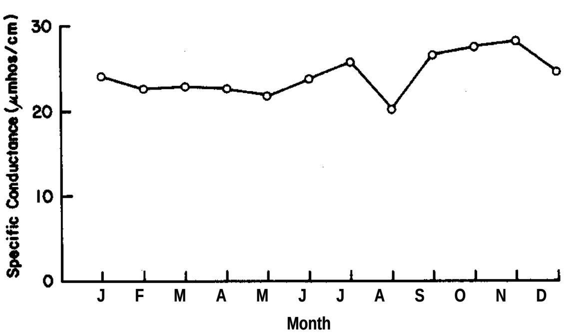

Figure5 .--Average monthly specific conductance of runoff from all watersheds combined for the 1977-1981 period.

Average turbidities ranged from about 10 to 32 IVTU, but differences among the four watersheds were not significant. The two undisturbed areas had the lowest turbidities in runoff water, followed in order by the shelterwood removal and clearcut-burn areas. This sequence follows the expected pattern based on relative surface disturbance in the watersheds. However, most sediment from the two disturbed watersheds probably came from the stream channels, since the ground surface generally had some litter or vegetative cover except the **clearcut** area immediately after the burn. The fact that turbidities also are affected by other impurities, such as organic compounds, should be borne in mind in assessing results.

H+ concentrations (pH) in runoff during the 1977-1981 period were significantly lower on WS-1 than all other watersheds (Table 3). Average pH of runoff water fram WS-2 was also significantly higher than WS-3 and WS-4. In the 1973-1977 period, differences among the watersheds were not significant, but monthly averages were. Average annual pH values show the differences among **watersheds**, with WS-1 and WS-2 reflecting the extremes (fig. 6). The plotted data also indicate a general decline in pH levels from 1976 to 1978. The cause of this change is not known, although atmospheric deposition is suggested. Watersheds 3 and 4 seem to be recovering from the 1978 low. The slight decline in 1981 on WS-1 and WS-2 may be showing seasonal effects since the data represent only the first 6 months of the year. A similar decline in pH of surface water, but of lesser magnitude, was found in Illinois during the same time period (Brozka, Rolfe and Arnold 1981). Monthly differences in pH during the early period suggest that seasonal trends exist (fig. 7). Average pH tended to increase in the spring and early summer months when precipitation is greatest, then decline in the drier months until soil water recharge begins and temperatures decline in the fall.

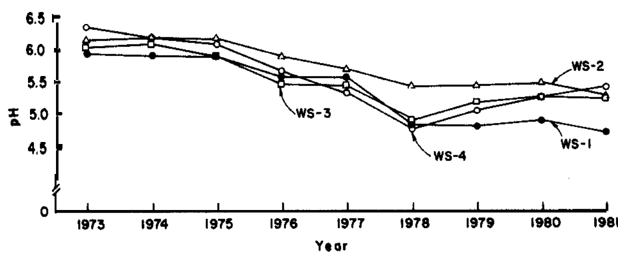

Figure6 .--Average pH of runoff by watershed and year.

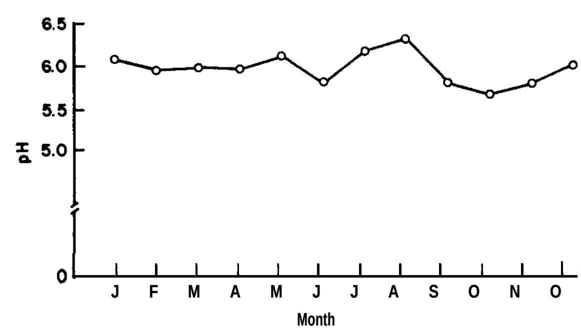

Figure7 .--Average monthly pH of runoff from all watersheds combined for the 1973-1977 period.

SUMMARY

Overall nutrient levels and other properties of runoff from the four watersheds were generally within the range of those previously reported in other areas (Bond 1979; Brozka, Rolfe and Arnold 1981; Douglass and Swank 1975; Hewlett 1979; Lewis and Grant 1979; Peterson and. Rolfe 1982).

Final harvest cutting of a shortleaf pine shelterwood stand and burning plus planting did not significantly increase outflow of most nutrients. The initial thinning plus hardwood deadening in the original stand and clearcut plus hardwood deadening may have strongly influenced results.

Turbidities reflected the treatment effects, but levels in runoff were not significantly different. Specific conductance levels were relatively low, but followed the concentration trends of several nutrients.

The pH levels in runoff varied significantly among the watersheds, but was not related to the treatments. Average pH values showea a general decline in several consecutive years during the study period.

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BIOLOGICAL RELATIONSHIPS BETWEEN WILDLIFE

AND SOUTHERN FORESTS: STATE OF THE ART[1/] [2/]

Ernest A. Gluesing and Donna M. Field[3/]

Abstract--The literature was reviewed to determine the state of current knowledge about the functional relationships between wildlife and southern forest ecosystems. Food habit studies were examined for knowledge on nutrition, digestion, energetics, and diet preference. Home range studies were examined for energetics. The reviewed suggest that even though a substantial number of food habits and home range studies have been conducted on a variety of species, little is known about how the nutritional value of foods and changes in diet composition affect growth, survival or reproduction. Similarly, little is known about the bioenergetics of home range, the minimum amount of habitat a species requires, or how changes in vegetative structure and species density affect the dynamics of animal communities.

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IMPACTS OF SILVICULTURAL

PRACTICES IN LOBLOLLY PINE PLANTATIONS

ON WHITE-TAILED DEER HABITAT[1/]

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Abstract.--Silvicultural practices such as burning, thinning, spraying, and fertilizing within pine plantations impact on white-tailed deer food (forage, mast) quantity, quality, digestibility, palatability, and availability. Other aspects of deer food, namely diversity, stability, and distribution (spatial, seasonal), and cover, are affected by practices within and between plantations, such as setting (stand) site preparation, size, shape and situation (interspersion).

INTRODUCTION

To meet the Nation's future demand for wood products about 30 million acres of idle or poorly stocked pine sites will have to be planted to high yield pine plantations (Mann 1975). During an average year 1.53 million acres of private and public land across the South are planted to pine (Sou. For. Institute 1979), and at the end of 1978 there were about 12 million acres of pine plantations in the Southeast (Knight and Sheffield 1980). Rotation length might be 35 years and management will be intensive (Koch 1980).

White-tailed deer (*Odocoileus virginianus*) populations across the South have greatly increased in the past several decades and are a very important game species (Steffen 1981). The purpose of this paper is to summarize the impacts of silvicultural practices in pine plantations and deer habitat conditions.

METHODS

Loblolly pine (*Pinus taeda* plantations in east central Mississippi and west central Alabama were studied from 1971-82. Plantations were located in the interior flatwoods (avg. SI 68 ft) and hills (avg. SI 64 ft) on a 25-year base and most plantations were on sites formerly occupied by pine-hardwood forests. The forests were clearcut, site prepared (tree crush and burn; mist-blow and tree-inject; or shear, rake, disk, and bed), and were hand-planted on an average spacing of 7 x 8 ft. Plantation size varied from 80 to 640 acres.

Deer forage (grass, forb, vine, woody) abundance on treated (burned, thinned, etc.) and untreated pine plantations was determined by the ranked-set sampling method (Halls and Dell 1966). Samples were taken in the peak of biomass period, August, and during the period of minimum forage abundance, February. Only new-growth, green, palatable parts of plant species usually eaten by deer in this area (Warren and Hurst 1981) were hand-picked or clipped to a height of 5 ft, placed in paper bags, oven-dried for 72 hours at 176° F, and weighed.

RESULTS

Forage in Untreated Plantations

Deer forage in August was least abundant on 1-year-old plantations that had received the most intensive site preparation, bed or bed and apply an herbicide. No differences in forage related to type of site preparation were detected.after age 1.

Forage increased on plantations from age 2-4 and peaked at age 5 at about 500 lbs/ac. Forage declined during the next 5 years to 100 lbs/ac (age 10) and 50 lbs/ac at age 12 (Hurst and Warren 1980). In February forage averaged

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77 lbs/ac at age 1, 21 lbs/ac at age 5, and 4 lbs/ac at age 12 (Hurst and Warren 1980). Deer forage on any given area would be affected by soil/site conditions, spacing and seedling survival rate.

Mature pine-hardwood forests, the type being converted to pine plantations, had 64 lbs/ac (Aug.) and 7 lbs/ac (Feb.) of deer forage. The forests also produced an average of 36 lbs/ac of acorns (dry wt.) and about 8 lbs/ac of other hard and soft mast (Hurst and Warren 1980).

Forage in Treated Plantations

Burning, thinning (precommercial and commercial), fertilizing, and combinations of these practices increased deer forage abundance in February (fig. 1). The use of herbicides for pine release would decrease deer forage in February.

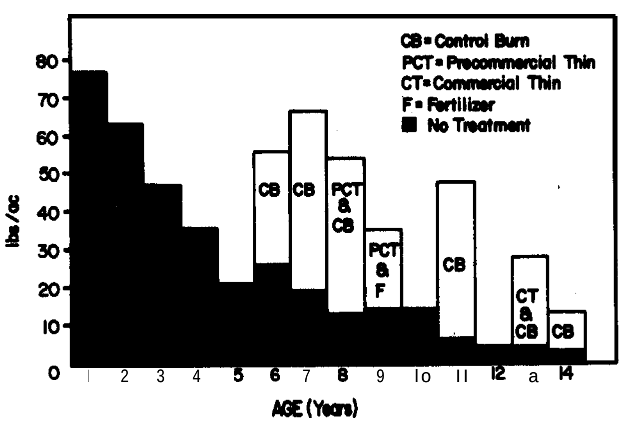

Figure 1.--Deer forage in February on untreated and treated Loblolly Pine Plantations.

Herbicides used for pine release in 4- and 5-year-old plantations reduced deer forage in August by 46%. Some recovery of forage was noted in the second growing season after spraying (Easley 1977).

Controlled burning of plantations in late winter at ages 5, 7, 10 and 13 increased deer forage in August to 544, 579, 244, and 235 lbs/ac respectively. The increases amounted to 26, 63, 68, and 94% above forage amounts in unburned plantations. Forage declined 52% (age 9) and 33% (age 12) in the second year after burning. Burning brought the forage into the deer's feeding level (up to 5 ft), and promoted new-growth on all vegetation (Hurst and Warren 1980, Hurst et al. 1980).

Precommercial thinning to 450 trees/ac at age 7 increased deer forage in August from an average of 300 lbs/ac on unthinned plots to 578 lbs/ac on thinned plots in the first and second years after treatment. In August of the third year after thinning there were 291 lbs/ac on thinned plots and 181 lbs/ac on unthinned plots (Hurst and Warren 1980).

Precommercial thinning and control burning of a 7-year-old plantation resulted in 544 lbs/ac of forage on thinned-burned plots compared to 114 lbs/ac on untreated plots the first August after treatment, and 555 lbs/ac (treated) compared to 137 lbs/ac (control) in the second August (Hurst et al. 1980).

Precommercial thinning and fertilizing (urea) produced more (648 lbs/ac) forage than just thinning (576 lbs/ac) the first August after treatment. The second year after treatment there was no difference between thinned-fertilized (544 lbs/ac) and thinned (579 lbs/ac) (Hurst and Warren 1980).

A 7-year-old plantation that had 235 lbs/ac of forage (August 1977) was fertilized (urea) in March 1978 and forage increased to 430 lbs/ac in August 1978. Forage declined to 185 lbs/ac the next August (age 9) (Hurst et al. 1982).

Precommercial thinning and pruning up to 9 ft (avg. tree height of 18 ft) was conducted on B-year-old plantations, and it appeared that pruning would prolong the increase in deer forage caused by thinning.

Commercial thinning and control burning of 13-year-old plantations increased deer forage to 291 lbs/ac (age 13) and 383 lbs/ac (age 14). These same plantations had an average of 23 lbs/ac at age 12 (Hurst and Warren 1982).

Other Deer Foods

In addition to forage, deer eat hard and soft mast and fleshy fungi (mushrooms). Clear-cutting and intensive site preparation removed most of the hard mast potential from plantations, and use of herbicides and fire in short rotations will not permit much hard mast production.

The amount and variety of soft mast produced by trees, vines and shrubs in mature pine-hardwood forests was decreased by conversion to plantations. Some forest species, e.g. dogwood (*Cornus florida*) and black gum (*Nyssa sylvatica*), produced fruit in young plantations (Campo and Hurst 1980). Soft mast production peaked at 83 lbs/ac on 5-year-old plantations, but the fruit produced was mostly blackberry (*Rubus argutus*), which fruits in the summer. Burned windrows had the highest fruit production (Campo and Hurst 1980). Soft mast production appeared to increase after commercial thinning of plantations. Length of burning rotations will affect soft mast production in plantations.

Mushrooms were very abundant in the winter months on burned **windrows** of bedded plantations at age 1 and 2 then declined rapidly at age 3. Pine-hardwood forests had more mushroom biomass than pine plantations in non-winter months and plantations over **4-years-old** (Hurst and Johnson 1980). Mushroom abundance seemed to increase in commercially thinned-burned plantations.

Other Deer Habitat Conditions

Deer cover requirements in the southeast are not well documented, but it is generally believed there are no special cover types. Qualitative characteristics of deer cover have not been described. Vegetative density and structure of pine plantations is usually dense, "jungle-like," and provides adequate cover. Cover is lacking on intensively site prepared tracts well into the first growing season. Deer do use the very open, bedded-sprayed tracts for foraging even in the first growing season.

Water is not thought to be a limiting factor for deer in the South. Major plant species eaten by deer in plantations contained an average of 65% water (Mawk 1976). Establishment of **stream-**side management zones, hardwood leave strips, fire suppression ponds, and water holes for wildlife maintain or increase water sources for deer.

Other Forest Management Practices

Streamside management zones on major streams and creeks and Hardwood Leave Strips on narrow (inaccessible) drainage-ways provided cover, some mast, travel lanes, and forage (Hurst and Warren 1980).

Access roads within plantations were planted to grass/clover which provided cool season forage. Company and county roads were day-lighted which increased deer forage production on roadsides.

DISCUSSION

Important components of deer habitat are food, cover, water, and space. Apparently southern deer do not have any special reproductive or survival requirements with regard to cover. Space and water are seldom limiting factors. Food is the critical factor but habitat capacity can not be evaluated solely on available, preferred forage dry matter (Blair et al. 1977). Some attributes of food are quantity, quality (nutritional content), distribution (spatial, temporal/seasonal), palatability (plant characteristics such as chemical content, succulence), digestibility, availability (within deer's feeding range, up to 5 ft), and diversity (vegetative types). Silvicultural practices directly or indirectly affect all aspects relating to deer food.

Burning, thinning, pruning, and fertilizing increased deer forage abundance in pine plantations. The increases in forage must be considered temporary, lasting only 1 year if just burning or fertilizing occurred, and perhaps 2 to 3 years for combinations of burn-thin, **thin-**fertilize. Browse plants growing in openings (thinned plantations) not only yield more twig rowth (browse) but also produce more fruit 4Halls and Alcaniz 1968).

Herbicides reduced deer forage abundance, but by top-killing the competing hardwood brush layer some sprouts and more desirable vegetation (vines, forbs) might result (Blair and Feduccia 1977).

Silvicultural practices also affect forage quality. Burning improved forage palatability, availability, and nutritional (protein, Ca, P) content (Lay 1957, Stransky and Halls 1976). Fire maintained forage **productivity** and increased digestibility (Lewis et al. 1982). Rapidly growing, succulent plant tissues were more nutritious and more digestible (Blair et al. 1977). Fertilizing plantations resulted in significant increases in deer forage (Kinard 1977, Hurst et al. 1982); however, nutrient content of forage from fertilized sites was not significantly greater than that from unfertilized sites (Kinard 1977). Plants (forage) from fertilized areas could be of increased value to deer in that they are more succulent (new-growth, rapid growth) thus more palatable and more digestible, yielding more metabolic energy (Heady 1964).

Deer have food preferences, which are a function of palatability. Palatability is determined by plant characteristics (chemical content, succulence, etc.). Silvicultural practices affect plant growth and contents--deer forage quality. Deer ate plant species usually rated as undesirable for deer on recently burned plantations (Warren and Hurst 1981). The same relationship probably exists with plants on fertilized plantations.

Deer feed upon a variety of plant types or parts and it has been documented that nutrient yield and digestibility of deer forage varies by season in pine plantations (Blair et al. 1977). The importance of having a diversity of vegetation to insure adequate nutrient levels has been demonstrated (Varner et al. 1977). Plant diversity can be accomplished through silvicultural practices and planning, to provide various successional stages or habitat types (age classes). Food diversity can be planned, manipulated through setting (stand) size, shape, and situation (surrounding age classes, habitat **types).** The **silviculturist/forest** manager manipulates deer habitat and he can increase interspersion (juxtaposition, edge, diversity) by planning pine plantation establishment and practices.

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SQUIRREL DEN TREE MANAGEMENT: REDUCING INCOMPATIBILITY WITH TIMBER PRODUCTION IN UPLAND HARDWOODS[1/]

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Abstract.--Characteristics and densities of eastern gray squirrel den trees in five upland hardwood habitats on the Cumberland Plateau were determined. The relationships between species, siee, age, and vigor of trees useful for selecting the beet current and potential den trees are discussed. Squirrel densities were estimated with time-area counts. Mast production not lack of dene limited squirrel populatlone. Management recommendations that would increase timber production and increase or have little impact on squirrel production are given.

INTRODUCTION

The Impact of silvlcultural practices on wildlife habitat is a major concern of forest managers. Although most wildlife biologlets recognize habitat manipulation by silvlcultural practices as the most efficient and lasting means of Improving habitat (Halls and Holbrook 1980, Trlmble et al. 1974), some incompatibilities between intensive timber management and wildlife dependent on tree cavities are apparent. Trees with cavities are removed and cavity formation is arrested during Intensive timber management. Thus, a loss of cavity dependent wildlife would occur.

To ensure that cavities are available, recommendations to leave cavity-trees unharvested have been made (Uhlig 1955, U.S. Forest Service 1971, Sandereon 1975, Evans 1978, Conner 1978, Evans and Conner 1979, McComb and Noble 1981). However, multiple-use recommendations to provide proper density and temporal and spatial distribution of cavity-trees for wildlife should consider adverse impacts on timber production. Timber production may be needlessly reduced if future stand development and expected life span of the cavity-trees are not considered. Existing stand conditions should be considered. Recommendations made for intensively managed forests have little applicability to high-graded hardwood stands. In these unmanaged stands, numerour cavities are present but not fully utilized for nertlng (Gysel 1961, Sanderson et al. 1975, Carey and Healy 1981, McComb and Noble 1981). Low utilization of cavities indicates unsuitability or oversupply.

A major problem in managing hardwood stands is determination of the level of cull tree removal that optimizes timber and wildlife benefits. Which and how many cavity-trees should be left? How should they be distributed In the stand? How can a future supply of cavity-trees be provided under various harvesting methods? This study wae established to address those questions for unmanaged oak-hickory and mixed upland hardwood stands typical of the Cumberland Plateau region. Objectives of the study were: 1) to determine density of cavity-trees and other culls in various foreet stands, 2) to describe cavity-trees, 3) to determine characteristics which are useful in predicting occurrence of future cavities, 4) to observe use of cavity-trees by squirrels, and 5) to estimate squirrel population levels.

STUDY AREAS

Study areas were located on the University of the South's school forest at Sewanee, Tennessee, on the western edge of the Cumberland Plateau. Topography varies from the undulating plateau top to steep escarpment slopes or coves. Site productivity varies greatly with aspect and slope position. The upper and mid-cove slopes are good to excellent hardwood sites. Smalley (1982) descrlbes the climate, geology, topography, and soils of the Mid-Cumberland Plateau Region.

Composition and quality of the school forest are the result of site differences and past management, called individual tree selection but was,

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in actuality, logger's choice. The resulting high-graded forest contains many culls and regeneration developed in clumps or patches without additional stand treatments.

Five general forest habitats or conditions which typify most of the school forest were selected for study. On top of the plateau, undulating uplands and the intermittent drainages that submaturely dissect the plateau surface were sampled. In the coves, north aspect, south aspect, and old growth were sampled. On the undulating uplands, scarlet oak (scientific names in Appendix) and white oak predominate with lesser amounts of black oak, chestnut oak, pignut hickory, and mockernut hickory. In the more moist and productive upland drainages, red maple, blackgum, and yellow-poplar are abundant. The coves contain mixed hardwood forests with a large number of overstory species. The most abundant species are northern red oak, white oak, pignut hickory, shagbark hickory, chestnut oak, and yellow-poplar. The mesic species of Braun's (1950) mixed mesophytic forest are common. Although present in other mixed mesophytic forests, American beech, black cherry, and eastern hemlock are rare or absent. The mesic species are more abundant on the cooler northern aspects. The old growth habitat is on a north aspect and over-mature with many large oaks and hickories now dying.

For discussion , the five habitat types will be called undulating upland, upland drainage, south cove, north cove, and over-mature cove.

METHODS

Each habitat type was sampled with six 1.24 acre rectangular transects, 70 feet by 769 feet. Two transects were randomly located at three different locations, allowing 7.4 acres in each habitat type and totaling 37 acres in the study. Transects were located in stands undisturbed for the past 20 years. Each transect was thoroughly searched for all cavities before leaf development in March, 1979. Searching with binoculars, three observers recorded (but did not verify by climbing) all cavities which appeared to penetrate the interiors of the trees. Cavities were classified as squirrel dens, squirrel escape cavities, or bird nest cavities. Most cavities classified as squirrel dens, and possibly some classified otherwise, were suitable for rearing young.

Descriptive data were collected from den trees to determine whether certain characteristics can predict potential cavity-producing trees. Stand tables and tree quality class for all trees five inches d.b.h. and larger were estimated by sampling four 0.05 acre quadrats in each transect. Potentialoverstory species were classified as desirable, acceptable, or cull. Den tree composition and size distribution were compared to general conditions by using chi-square tests. Top condition, basal condition, and number of blind knots or limb stubs larger than two inches in diameter were determined for selected trees seven inches d.b.h. or larger. Frequency distributions of various categories of each attribute were determined for both cavity and non-cavity trees. Chi-square tests were used to determine whether the distribution of cavity-trees was different from the distribution of non-cavity trees.

Cavity usage and squirrel density were determined by visual monitoring 24 transects. A minimum of three permanent observation points was established in each transect. All den trees were visible from at least one point. Time-area counts to estimate squirrel density were conducted. Each transect was monitored once weekly for five weeks in both the spring and fall in 1980 and 1981. In 1979 the spring observation period was six weeks, and the fall four weeks. Monitoring periods corresponded to when young squirrels were becoming active outside the dens. Den trees were observed for 253 hours per year, and time-area counts were conducted during 240 hours. Each den tree was observed for a minimum of 3.3 hours yearly. Transects were monitored for three years because of expected fluctuations in both squirrel density and use of den trees. Mast production by species in each habitat type was estimated in late August of 1979 and 1980.

RESULTS AND DISCUSSION

Density of Cavity-Trees and Other Culls

A total of 82 den trees and 255 trees with escape cavities were located. Undulating uplands had the greatest density of den trees and upland drainages had the greatest density of escape cavities (Table 1). The number of den trees per transect ranged from 0 to 7, and the number of escape cavity-trees ranged from 2 to 26. The highest combined density per acre of cavity-trees was 13.8 in upland drainages.

Table 1.--Density of squirrel dens and escape cavities in upland hardwoods on the Cumberland Plateau

Cavity Type	Habitat Type[1]				
	U.D.	OM.C.	S.C.	N.C.	U.U.
	- - - - - - Density/acre[2] - - - - - -				
Den	2.3a	2.7a	1.6a	1.2a	3.2a
Escape	11.5a	6.6ab	6.2b	6.1b	3.9b

1/ U.D. = upland drainage, OM.C. = over-mature cove, S.C. = cove with south aspect, N.C. = cove with north aspect, U.U. = undulating uplands.

2/ Means within rows not followed by a common letter differ ($P \leq 0.05$) as determined by Duncan's new multiple-range test.

The number of culls per acre ranged from 25 in the over-mature cove to 79 in upland drainages. Cull percent ranged from 25.6 in undulating upland to 47.3 in upland drainages. Cull percent was high in upland drainages because of abundant red maple and blackgum. Fifty-three percent of scarlet oaks larger than 10 inches d.b.h. was cull.

Characteristics of Escape Cavity-Trees

The location of escape cavities within the tree often determines their usefulness to squirrels. Cavities at the base of tree often contained sufficient decay to preclude use by squirrels. Most escape cavities in the upper bole could possibly serve as dens if more suitable cavities were lacking. In the upland habitats, limbs with cavities were usually too small to serve as dens, but in the cove habitats limbs were large enough to contain dens. Density per acre of trees with escape cavities in different parts of the tree is recorded below:

	Basal	Upper Bole	Limb
Upland Drainage	7.6	4.9	0.9
Undulating Upland	2.7	1.8	0.0
Overmature Cove	4.9	1.9	0.5
South Cove	4.9	0.4	1.1
North Cove	4.3	2.0	0.1

Some trees had cavities in more than one location. The percent of escape cavity-trees with basal cavities ranged from 65.1 percent in upland drainages to 78.3 percent in south coves.

In undulating uplands, 48.3 percent of the cavity-trees was scarlet oak. Other scarlet oaks had signs of internal decay, enlarged bases and fire scars without external cavity openings. Sourwood comprised 17.2 percent of the cavity-trees and six other species contained fewer cavities. In upland drainages, red maple was the most abundant cavity-tree and comprised 62.8 percent of thetotal. Of eight other species with cavities, the most abundant was white oak with 11.6 percent. In north coves, 16 species contained cavities and hickories comprised 26.7 percent of the total. Yellow-poplar with 11.1 percent was the only other species that comprised more than 10 percent of the cavity-trees. In south coves, hickories comprised a much larger percent, 56.5, of the cavity-trees. Most cavities were basal and probably a result of fire scarring. Nine other species contained cavities, northern red oak with 10.9 percent being most abundant. In the over-mature cove, 13 species contained cavities. Sugar maple, hickories, northern red oak, and blackgum comprised, respectively, 28.6, 20.4, 16.3, and 10.2 percent of the cavity-trees.

The size class distribution of the cavity-trees reflected general stand conditions. In habitat with more large trees, a higher percent of cavity-trees was in the larger size classes. The percent of cavity-trees in the less than seven inch d.b.h. size class was much smaller than the percent of total trees in that size calss. The percentages of cavity-trees and of total trees were about equal in the 7-10 inch size class, but in the larger size classes the percent of cavity-trees were much higher than the percent of total trees. It follows that larger trees were more likely to contain escape cavities.

Characteristics of Squirrel Den Trees

The characteristics most useful for predicting den occurrence were species, size, presence of entry points for decay organisms, and tree vigor, which is affected by interactions among the previous factors.

Species and Size Class Distrbutions

Differences among the habitat types were apparent (Table 2). Certain species and diameter size classes produced more den trees. The most productive species and sizes varied among habitat types because of differences in species composition and size class distribution. In both the undulating uplands and upland drainages, scarlet oak is the preferred species to manage for dens because numerous relatively small scarlet oaks contained dens. Seventy-six percent of the den trees were scarlet oak and 73 percent of these were in the 11-15 inch size class. Red maple should be retained in upland drainages, but red maple dens are usually less suitable than scarlet oak dens. In white oak and hickories, dens were usually found only in large trees or in low vigor trees. Yellow-poplar, a rapid growing species, contained cavities only in trees over 20 inches in diameter.

In both north and south coves, northern red oak, hickories, and blackgum were the most abundant den trees. When data for the two types were combinded, northern red oak, blackgum, and sassafras had significantly more den trees than expected. All blackgum greater than 16 inches d.b.h. contained either escape cavities or dens. Of the 12 species that contained no dens, yellow-poplar and chestnut oak predominated.

In over-mature coves, nine species contained dens with northern red oak and hickories predominating. White ash was the only species with significantly more dens than expected and no species had significantly less than expected. Chestnut oak and white oak were the most abundant species having no dens.

The proportion of trees with dens increased as diameter size class increased and a positive deviation from the expected number of den trees existed in the 16-20 inch and larger size classes in all habitat types. Thus the 16-20 inch size class seems to be the threshold size where trees become more likely to contain dens. In scarlet oak, the threshold size is 11-15 Inches.

Vigor and availability of larger trees affected the size class distribution of den trees. In undulating uplands, den trees in the 11-15 inch size class were numerous; low vigor scarlet oak in this size class was abundant and larger trees were scarce. In upland drainages and cove habitat types where more large trees were available, the percent of trees in the 11-15 inch class with dens was much

Table 2.--Density distribution of squirrel den trees compared to the distribution of all trees >7 inches d.b.h. in upland hardwoods on the Cumberland Plateau

Species	D.B.H. Size Class in Inches: 7-10	11-15	16-20	21-25	>25	Species Total(%)	All Trees(%)	Percent With Dens
Undulating Upland								
	---	---	No./7.4 a	---	---	---	---	-- % --
Scarlet Oak	1	16	4	0	0	21(88)	402(47)	5.2
White Oak	0	1	1	0	0	2 (8)	204(24)	1.0
Hickories	0	0	0	0	1	1 (4)	38 (4)	2.7
Others	0	0	0	0	0	0	209(25)	0.0
Size Class Total (%)	1 (4)	17(71)	5(21)	0	1 (4)	24(100)		
All Trees (%)	538(63)	247(29)	68 (8)	0	0		853(100)	2.8
% With Dens	0.2	6.9	7.4	0	-		2.8	
Upland Drainages								
Red Maple	0	0	3	2	3	8(47)	241(26)	3.3
Scarlet Oak	0	3	2	0	0	5(29)	56 (6)	8.9
White Oak	0	0	0	1	0	1 (6)	290(32)	0.3
Yellow-Poplar	0	0	0	1	0	1 (6)	56 (6)	1.8
Post Oak	0	1	0	0	0	1 (6)	43 (5)	2.3
Chestnut Oak	0	1	0	0	0	1 (6)	62 (7)	1.6
Others	0	0	0	0	0	0	161(18)	0.0
Size Class Total (%)	0	5(29)	5(29)	4(24)	3(18)	17(100)		
All Trees (%)	470(52)	297(33)	99(11)	25 (3)	18 (2)		909(100)	1.9
% With Dens	0	1.7	5.0	16.2	16.1		1.9	
Overmature Cove								
N. Red Oak	0	0	1	1	4	6(30)	105(20)	5.7
Hickories	0	0	1	1	3	5(25)	167(31)	3.0
White Ash	0	0	1	1	0	2(10)	12 (2)	16.7
Yellow-Poplar	0	0	0	1	1	2(10)	19 (4)	10.5
Buckeye	0	0	0	0	1	1 (5)	19 (4)	5.3
Black Locust	0	0	1	0	0	1 (5)	0	
Cucumber Tree	0	0	1	0	0	1 (5)	0	
Black Cherry	0	0	1	0	0	1 (5)	6 (1)	16.7
Sugar Maple	0	1	0	0	0	1 (5)	74(14)	1.4
Others	0	0	0	0	0	0	136(25)	0.0
Size Class Total (%)	0	1 (5)	6(30)	4(20)	9(45)	20(100)		
All Trees (%)	142(26)	161(30)	130(24)	56(10)	49 (9)		538(100)	3.7
% With Dens	0.0	0.6	4.6	7.2	18.2		3.7	
South and Worth Coves Combined								
	---	---	No./14.8 a	---	---	---	---	-- % --
N. Red Oak	0	3	3	1	0	7(33)	166(11)	4.2
Hickories	0	3	1	2	0	6(29)	488(33)	1.2
Blackgum	0	0	3	1	0	4(19)	24 (2)	16.7
Black Walnut	1	0	0	0	0	1 (5)	43 (3)	2.3
Black Locust	0	0	1	0	0	1 (5)	31 (2)	3.2
White Oak	0	0	0	1	0	1 (5)	303(20)	0.3
Sassafras	0	0	0	1	0	1 (5)	6(<1)	16.7
Others	0	0	0	0	0	0	429(29)	0.0
Size Class Total (%)	1 (5)	6(29)	8(38)	6(29)	0	21(100)		
All Trees (%)	705(47)	507(34)	204(14)	74 (5)	0		1490(100)	1.4
% With Dens	0.1	1.2	3.7	8.1	0		1.4	

lower. In north and south coves, most den trees in this size class were suppressed and had greatly reduced crowns. In the over-mature cove, dens were concentrated in low vigor trees larger than 25 inches in diameter. Vigorously growing trees with well developed crowns, regardless of size, contained few cavities.

Age and Tree Growth

In upland habitat types, the age of 16 scarlet oak dens were determined. Age ranged from 72 to 125 years, averaging 94 years. Thus 80-year rotations would produce few den trees even in stands were scarlet oak is abundant. If **90-year-old** scarlet oak dens were left in a **clear**-cut, few dens would be present in 30 years. However, if large patches of trees from 30 to 50 years of age were retained, dens and food would be available simultaneously. Regardless of tree vigor, retained scarlet oaks 7-10 inches d.b.h. should produce numerous den trees in 40 years. Basal cavities and deterioration prevented gathering data on red maple. Five white oak den trees ranged from 19 to 22 inches d.b.h. and diameters 40 years ago ranged from 15 to 17 inches. The ages of three trees were 152, 170, and 224 years. Because species in the white oak group grow and develop decay slower than red oak species, white oak species will produce cavities only when larger and older trees become available. But once dens are formed in the durable white oaks, they remain usable much longer than dens in species with softer wood.

In the coves, northern red oak waa the only species in which more than one den tree could be aged. Age from six trees ranged from 81 to 157 years. Tree vigor varied greatly and will influence what size of trees should be retained to produce dens in the future. If trees are vigorous, larger trees should be retained. Hickories were growing much slower than red oaks. The only hickory aged was 228 years old. The d.b.h. 40 years ago of seven hickories ranged from 11.5 to 23.6 inches. Hickory den trees were numerous probably because many low vigor, cull hickories were not cut during prior harvests. As with white oaks, dens in hickories should persist for many years.

Availability of Entry Points for Decay Causing Organisms

Because decay organisms are vital to the cavity formation process, the presence and number of injured points should be useful in predicting cavity occurrence. Injuries to basal, top, and bole portions of den trees were described. Damage to tree tops seemed most conducive to den formation. Tops of den trees were damaged more than expected in four of five habitat types. Damaged tops had either been broken off or more than two lateral branches became dominant vertical stems. Extensively damaged tops which failed to heal offered excellent entry points for decay causing organisms. Minor damage to tops that resulted In major forks did not promote den formation. Although more den trees than expected had basal cavities, reduction of tree vigor caused by basal rot probably had a greater effect on den formation than the movement of decay up the tree. Even though the number of large blind knots on den trees was not greater than expected, limb die-back may still promote decay. Trees with or without dens simply had similar amounts of dead limbs or blind knots.

Squirrel Abundance

Eastern gray squirrel density varied between habitat types and time periods (Table 3). Variation was greater among time periods than among habitat types. Relationships between density of den trees and squirrel density on each transect were low. Den tree density had little impact on the large fluctuations in squirrel density over time. Next to the highest squirrel density, 74 per 100 acres, was recorded for north coves, which had the lowest density of den trees. The low density of squirrels in over-mature coves was of particular interest because old-growth forests with large trees and numerous dens are often considered prime squirrel habitat. On all habitat types, squirrel populations increased or decreased rapidly regardless of den tree density. During the three years of this study, some factor other than den tree density controlled squirrel abundance.

General trends in squirrel abundance were closely related to mast production. Hard mast production was better in 1979 than 1978. Squirrels responded to the increase in food supply and populations increased in 1980. After poor mast production in 1980, squirrel populations decreased drastically in 1981 in all habitat types.

The relationships between squirrel abundance, den tree density, and hard mast production indicate that mast production and not den tree density limits squirrel abundance in unmanaged, low-quality forests on the Cumberland Plateau. At this time, management actions that increase mast production should be a top priority of squirrel management.

Use of Den Trees

The use of den trees was visually confirmed only rarely. Either few of the available dens were used to rear young or the monitoring technique did not efficiently detect usage. Although 88 den trees were monitored, usage of dens was detected in only 2 trees in 1979, 6 trees in 1980, and 3 trees in 1981. Thus, observed usage was low even in 1980 when squirrel populations were highest.

Recent gnawing around cavity entrances also indicates den usage by squirrels. Thirty-nine percent of the den trees had signs of recent gnawing in April, 1979; 22 percent in August, 1979; and 27 percent in April, 1980. Although signs of fresh gnawing indicated squirrel usage greater than that confirmed by visual monitoring, both methods indicated that many available den trees were not

Table 3.--Density of squirrels per 100 acres determiued from time-area counts at different times In upland hardwood habitats on the Cumberland Plateau

Habitat Type	Den Trees/ 100 a	1979		1980		1981	
		Spring	Fall	Spring	Fall	Spring	Fall
		Squirrels/100 a					
Undulating Uplands	320	11	9	44	54	0	29
Upland Drainages	230	14	21	79	67	12	17
South Coves	160	10	49	7	32	6	0
North Coves	120	10	74	26	54	0	4
Over-Mature Coves	270	1	34	4	89	1	0

used. The relationship between recent gnawing and squirrel abundance was low.

DEN TREE MANAGEMENT

Recommendations are for squirrel management only and do not consider the needs of other cavity-dependent wildlife.

Density and Distribution of Den Trees

The number of den trees provided should provide cover for the number of squirrels that can be supported by hard mast production. If the forest is not old enough to produce hard mast, no den trees are needed. In uneven-aged forests, many trees are too small for mast production and one high quality den tree per two or three acres should suffice. In even-aged forests greater than 60 years old, one den tree per two acres will support high squirrel populations. low vigor den trees, which have little effect on growth of surrounding trees, can provide supplemental dens. At recommended den tree densities, low mast production would be the limiting factor on squirrel abundance in most years.

Because squirrels have small home ranges, den trees should be distributed within each 20 acres of the forest. Within each 20 acres, den trees can be scattered or clumped. In the unmanaged stands inspected during this study, den trees were often closely clumped.

Selecting Trees to Leave

Prehaps the most complex phase of den tree management is deciding what trees to leave. Suitable den trees should be provided when they are needed, either at present or sometime in the future. If den trees are needed at present, it is impartant to select trees with cavities suitable for rearing young. Some cavities, such as those associated with extensive basal rot, are not suitable nesting sites. Evans and Conner (1979) identified the best quality nest sites for nongame birds as live trees having decayed heartwood in the upper trunk or main limbs surrounded by living sapwood. Cavities in such trees also produce the most suitable squirrel dens because solid wood is above, below, and around the cavity. These cavities provide the maximun protection from adverse weather conditions and predators. The need to select suitable cavity-trees has been discussed by Uhig (1955); Sanderson (1975); Scott, Whelan, and Alexander (1978) and numerous other authors.

In most upland hardwood stands, many cull and cavity-trees are present, but few are suitable den trees. On the upland drainages of the present study, 79 cull trees per acre were present but only 3 were suitable den trees. Preservation of den trees cannot be used as an excuse for failure to improve the quality of upland hardwood stands.

Other considerations for selection of trees to leave are: (1) planned future management of the stand, (2) impact on growth of surrounding trees, (3) length of den tree usability, and (4) food production by the den tree. Under uneven-aged or even-aged management systems, den trees will be needed at certain times in the future. To improve the chances that a tree selected today will actually provide a future den, the relationships between species, age, size, vigor, and availability of entry points for decay-causing organisms are important. Four general relationships were applicable to all stands.

The first was that most dens were found in the oldest or largest trees in the stand. If dens are to be provided especially with even-aged management, some trees older and/or larger than the majority of trees will have to be present. The second relationship was that some species were more prolific producers of dens than others, and the tree size at which dens become common varied with species. Longevity, durability of its wood, and susceptibility to defect and decay are species characteristics useful in determinging the correct size of tree to leave. The third relationship was that regardless of species or size, trees low in vigor were more likely to contain dens. Thus, trees selected to produce future dens should be retained in large clumps with density high enough to insure inter-tree competition. Side competition also promotes limb dieback, which supplies entry points for decay-causing organisms. This leads into the last general relationship. As the number and types of decay entry points increase, the likelihood of den formation increased. Top damage promoted den formation better than limb dieback or basal damage.

Providing Den Trees After Clearcutting

Because silvicultural clearcutting removes all existing den trees and because few new dens would have time to develop before rotation age, some modification of clearcutting practices must be implemented to provide den trees in the new stands. The modification of leaving existing den trees, either singularly or accompanied by two or three additional trees, provides little positive benefits to squirrels because many of the trees are dead or gone before den trees are needed in the new stand. A better modification would be to leave at least one acre patches of poletimber and small sawtimber trees covering around 15 percent of each 20 acres within the clearcut. This practice would provide older and larger trees essential for den formation and also greatly increase within-stand diversity. These patches of older growth could be used to leave travel lanes through the clearcut, to reduce visual impacts, to provide an old-growth component throughout the forest, and to increase edge effect. The species, size, age and vigor relationships discussed in preceding sections would determine the size of trees to retain so that den trees would be available when needed.

The retained patches should be managed as inclusions within the stands and not as separate stands. Therefore, at the end of each rotation period, the retained patches should be harvested and other areas of the stand should be retained. The new areas to be retained should be selected early in the rotation period and thinning should not be conducted in these areas after trees reach seven to eight inches in diameter. After becoming fully regulated, a forest on an 80-year rotation would have about three acres of 160-year-old trees on each 20-acre block. Stream-side management zones and areas where timber management is uneconomical could be substituted for some of the retained area. Although some timber production would be lost because of slower growth and defect of some trees, many of the retained trees on good sites would be high quality veneer-sized trees. The higher value of large trees would partially offset the loss in growth.

Although maximum production of neither resource will be attained, the management suggestions made in this paper should maintain both timber and squirrel production at acceptable levels.

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APPENDIX

Common Name	Scientific Name
Black cherry	Prunus serotina Ehrh.
Blackgum	Nyssa sylvatica Marsh.
Black locust	Robinia pseudoacacia L.
Black walnut	Juglans nigra L.
Buckeye	Aesculus octandra Marsh.
Cucumber tree	Magnolia acuminata L.
Hickories	Carya spp.
Mockernut	C. tomentosa (Poir.) Nutt.
Pignut	C. glabra (Mill.) Sweet
Shagbrak	C. ovata (Mill.) K. Koch
Maples	Acer spp.
Red	A. rubrum L.
Sugar	A. saccharum Marsh.
Oaks	Quercus spp.
Black	Q. velutina L.
Chestnut	Q. prinus L.
Northern red	Q. rubra L.
Post	Q. stellata Wangenh.
Scarlet	Q. coccinea Muenchh.
White	Q. alba L.
Sassafras	Sassafras albidum (Nutt.) Nees
Sourwood	Oxydendron arboreum (L.) DC.
White ash	Fraxinus americana L.
Yellow-poplar	Liriodendron tulipifera L.

PINE UTILIZATION BY DEER IN YOUNG LOBLOLLY PINE PLANTATIONS IN EAST TEXAS[1/]

Patti L. Furrh and Andrew W. Ezell[2/]

Abstract.--A study of white-tailed deer food habits was conducted on young loblolly pine plantations in East Texas and 24 rumen samples collected seasonally over a one-year period were analyzed. The percent volume of pine was determined to evaluate the extent to which deer select pine as a forage item, and ranged from 0.0% to 31.4%, depending on season and study site. The study generally indicated that young pines are a non-preferred forage item, but may occur in the diet when preferred species are scarce. Heavy deer browsing on young pines could lead to damage, especially in times of food shortage and when pine seedlings are most susceptible to browsing damage, such as immediately after planting.

INTRODUCTION

With the increased popularity of clearcutting in the South, information pertaining to forage production and deer browse in clearcuts could serve to enhance our ability to create favorable deer habitat in East Texas, as well as assess the importance of pine as a potential deer food. White-tailed deer (*Odocoileus virginianus* Boddaert) are adaptable to many environmental conditions and may do well in areas intensively managed for pine pulpwood and sawtimber. However, the availability of food items in pure pine stands of certain ages and at oertain times of the year may be critical (Sheldon and Causey 1974). During these critical periods, depredation on young loblolly pines (*Pinus taeda* L.) by white-tailed deer may occur.

The extent to which deer select young pines as a forage item may best be evaluated by an assessment of the seasonal food habits of deer feeding in young plantations. The objectives of this study were to determine the species and specific plant parts eaten seasonally by deer feeding in young loblolly pine plantations, and to evaluate the extent to which deer select young loblolly pines as a forage item in young East Texas pine plantations.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-5, 1982.

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METHODS

Study Areas

The study was conducted on two Z-year-old loblolly pine plantations located in Angelina County near Diboll, Texas on land owned by Temple-Eastex, Incorporated. study Site I was a 253-acre plantation in the Renfro Hunting Club. Study Site II was a 214-acre plantation in the Tower Hunting Club. Both areas were clearcut, windrowed and burned, and planted in loblolly pine in 1980. Both sites were replanted in 1981.

Deer Collection

Rumen samples were obtained from 24 deer. Three deer older than 6 months were collected seasonally from each study site, with no regard to the sex of the animals. For the purposes of this study, winter was defined as the period from December 1 to February 29; spring from March 1 to May 31; summer from June 1 to August 31; and fall from September 1 to November 30. Deer collection was completed the middle month of each season.

Deer collecting was done at times when the deer were feeding, as the rumen was more likely to contain larger, more easily identifiable pieces of vegetation. The deer were killed within or along the edges of the clearcuts. Live weight, sex, age, antler description and general physical condition of each animal was recorded. The lower jaw was removed from each deer for age determination, which followed Severinghaus' (1949) method of tooth development and wear as criteria of age. Each deer was gutted and the rumen was laid out on a plastic bag. After the rumen was cut open, the contents were mixed by hand so a uniform sample could be obtained. Rumen samples were frozen *in* heavy plastic bags until laboratory analysis could be performed.

Rumen Analysis

Rumen analysis generally followed the technique described by Harlow and Hooper (1971). Any deviation from their technique is described in the following description of laboratory procedures. After thawing a bag of rumen contents, a one-quart sample was separated out by filling a one-quart jar. The quart of rumen material was washed through a series of three sieves: 3.51, 5.66, and 9.51 nun mesh sizes. The portion of rumen material held in the two larger sieve mesh sizes was identified to species when possible. The volume of each species was measured by the water displacement method, and each food item was tabulated into one of the following major food categories: green leaves, dry leaves, stems and buds, grasses and grass-like plants, fungi, and fruit. Any foods unidentifiable to species were also placed into one of these categories.

Material washed through into the smallest sieve mesh size was recorded as unidentifiable, finely ground material, and its volume was also measured.

Identification of plant parts to species was accomplished by intensive microscopic study and comparison. Most identifications were based on key vegetative characteristics including leaf and stem shapes, leaf margins, leaf apices and bases, leaf texture, veination patterns, glandular structures and surface characteristics such as pubescence.

Data analysis

One of the basic methods for volumetric evaluation of data, as discussed by Martin et al. (1946) is the aggregate volume method. The aggregate volume was determined for each plant species by summing the volumes for each series of rumen samples. In this study, a series was represented by three rumen samples collected from each study site in each season. Next, the volume summation was divided by the total identifiable food volume for three deer. This aggregate volume represents a percentage based upon the total identifiable food volume. Any volume measuring less than 0.1% of the identifiable volume was recorded as trace.

The frequency of occurrence of food items found in each rumen sample was derived from the number of samples in which a particular food item occurred. The rumen samples were grouped by season and the frequency of occurrence of major species eaten each season was calculated along with the frequency of occurrence of food items *in a* series.

Analysis of variance was used to test for significant ($P<0.05$) differences in the deer diet between seasons and between study sites. Separate analyses of variance were performed to test for significant differences in the volume of pine in the diet, as well as for significant differences between major food categories.

Vegetation Sampling

The net primary production of current leaves and stems of vegetation up to 5 ft (1.5 m) above ground was determined by the double-sampling method as described by Wilm et al. (1944). Two-hundred milacre quadrats were established in a grid pattern on each pine plantation.

The green weight of current growth was visually estimated on all quadrats. In addition, the growth was clipped up to 5 ft above ground level and weighed from 100 milacre quadrats located at every fourth sampling point (50 from each study site). Current growth was estimated and clipped by 3 classes: browse, grasses and grass-like plants, and forbs.

Two sets of data were obtained: one large estimated sample and a small sample of both estimated and actual fresh weights. A correction ratio was determined from the relationship of actual fresh tissue weights to estimated weights, and used to correct the estimates of fresh weights obtained from the large sample.

The fresh plant material collected from clipped quadrats was dried to constant weight in a forced draft oven at 65°C. Dry matter percentages were computed and biomass production data were converted to a dry-matter basis.

To help in the identification of rumen contents, plant specimens from both study sites were collected and preserved for reference purposes. Many of the same plants were collected seasonally since fresh growing parts often appear different from the older, mature plants. Each collected plant was preserved by pressing and drying (herbarium specimens) or by storing in 5% formalin. Plant nomenclature followed the *Manual of the Vascular Plants of Texas* (Correll and Johnston 1979).

RESULTS AND DISCUSSION

Rumen Analysis

During one year, January through December 1982, twenty-four rumen samples were collected, 22 of which have been analyzed at this point. These specimens were obtained from 8 male and 16 female deer and the major foods eaten seasonally by study area are listed in Tables 1 and 2.

Table 1. Percent by volume and percentage occurrence of principal plant species and plant parts consumed seasonally by deer from Site I.

Plant species and plant parts[1/]	Winter Vol.	Winter Occ.	Spring Vol.	Spring Occ.	Summer Vol.	Summer Occ.	Fall[2/] Vol.	Fall[2/] Occ.
	percent							
Solanum spp. (f)	58.0	67	-	-	-	-	31.1	50
Gelsemium sempervirens (l,s)	11.2	100		-	-	-	1.1	100
Plantago spp. (l)	8.7	67			-	-		
Pinus taeda (l)	5.8	100	1.9	67	-	-		
Ilex vomitoria (l,s)	3.5	100	2.3	67	0.5	33	0.4	50
Myrica cerifera (l,s)	3.4	100	-	-	-	-		
Lonicera japonica (l,s)	2.8	100	-	-	0.9	33		
Quercus nigra (l,f)	2.3	100	8.1	100	0.9	33	31.6	100
Smilax bona-nox (l)	0.7	33	9.1	100	-	-	0.9	50
Ilex decidua (l)	0.7	100	-		-	-		
Rhamnus caroliniana (l,s)	0.6	67	1.3	33				
Smilax rotundifolia (l,f)	0.5	67	3.5	33	12.1	67	1.1	100
Nyssa sylvatica (l)	0.5	33	-					
Rubus spp. (l,s)	0.5	67			14.8	100	1.7	50
Ilex opaca (l,s)	0.3	33	-				0.6	50
Callicarpa americana (l,s,f)	-	-	22.2	100	6.7	67	3.4	100
Vitis spp. (l,f)	-	-	13.1	67	16.6	100	3.6	100
Oxalis spp. (l,s)	t[3/]	33	8.6	100	-	-	0.4	50
Vaccinium spp. (l)	-	-	5.8	100	0.9	33		
Liquidambar styraciflua (l)	-	-	4.0	33	-	-	0.4	50
Berchemia scandens (l)	-	-	1.5	33	-	-	0.4	50
Hypericum spp. (l,s)	-	-	-		1.1	33		
Sassafras albidum (l)	-	-	-	-	0.9	33		

1/ l-leaves; s-stems and buds; f-fruit.
2/ Fall values based on analyses of 2 rumen samples.
3/ Amounts of less than 0.1% recorded as trace (t).

Table 2. Percent by volume and percentage occurrence of principal plant species and plant parts consumed seasonally by deer from Site II.

Plant species and plant parts[1/]	Winter Vol.	Winter Occ.	Spring Vol.	Spring Occ.	Summer Vol.	Summer Occ.	Fall[2/] Vol.	Fall[2/] Occ.
	percent							
Pinus taeda (l)	31.4	100	1.2	67	0.9	67	0.6	50
Ilex vomitoria (l,s)	27.1	100	1.9	67	0.3	33	1.9	100
Gelsemium sempervirens (l,s)	12.1	100	4.0	100	7.2	67	1.2	100
Myrica cerifera (l,s)	8.0	100	-	-	-	-	-	-
Plantago spp. (l)	4.1	33	-	-	-	-	-	-
Ilex decidua (l)	3.0	67	0.4	33	-	-	-	-
Nyssa sylvatica (l)	3.0	67	3.3	33	2.6	67	-	-
Rhamnus caroliniana (l,s)	2.0	33	6.2	33	-	-	-	-
Quercus nigra (l,f)	2.0	67	4.0	67	-	-	8.7	100
Smilax bona-nox (l)	1.0	33	1.7	67	1.4	33	1.6	50
Vitis spp. (l,f)	1.0	33	18.6	100	1.1	67	2.8	50
Ilex opaca (l)	0.4	33	-	-	-	-	-	-
Callicarpa americana (l,s,f)	-	-	22.4	100	2.6	67	39.8	100
Liquidambar styraciflua (l)	-	-	11.2	67	1.7	67	0.9	50
Smilax rotundifolia (l,s,f)	-	-	7.3	33	20.5	100	-	-
Vaccinium spp. (l)	-	-	2.1	33	-	-	0.3	50
Oxalis spp. (l,s)	-	-	1.9	67	-	-	-	-
Rubus spp. (l,s)	-	-	1.2	33	1.1	67	1.6	50
Lonicera japonica (l,s)	-	-	-	-	2.0	67	1.2	50
Berchemia scandens (l)	-	-	-	-	1.7	33	-	-
Sassafras albidum (l)	-	-	-	-	0.9	33	-	-
Cornus florida (l;f)	-	-	-	-	-	-	27.0	50
Helenium flexuosum (f)	-	-	-	-	-	-	0.6	50

1/ l-leaves; s-stems and buds; f-fruit.
2/ Fall values based on analyses of 2 rumen samples.

Winter Season

The greatest volume of pine was consumed during the winter season. On Site I, pine ranked fourth in aggregate volume consumed with **5.8%,** and was the number one food item on Site II with an aggregate volume of 31.4% (Fig. 1). On Site I seven items exceeded 1.0% aggregate volume and accounted for 95% of foods eaten. On Site II, 11 items exceeded 1.0% aggregate volume and accounted for 97% of foods eaten.

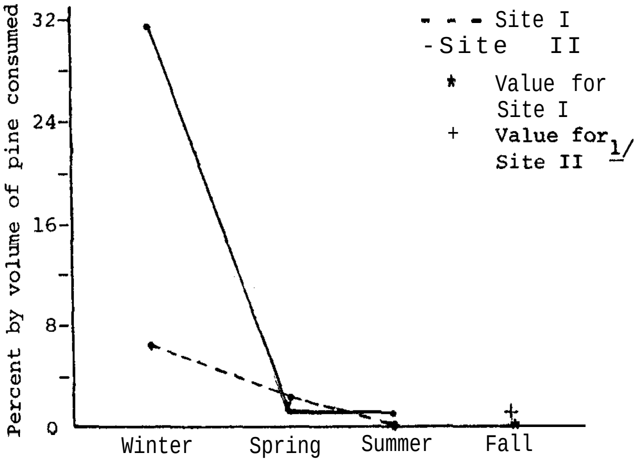

Figure 1. Percent by volume of pine consumed by twenty-two white-tailed deer, by season and study site.

1/ Values for Site I and Site II in the fall were based on analyses of 2 rumen samples from each site.

Foods selected in greatest amounts by deer on both sites were the leaves of yellow **jassamine** (scientific names are listed in **Appendix),yaupon,** southern waxmyrtle, plantain and pine. The fruit of nightshade was eaten heavily on Site I as were the leaves of Japanese honeysuckle (Table 1). **On** Site II, the leaves of Carolina buckthorn, deciduous holly, and **blackgum** were consumed in excess of 1.0% aggregate volume (Table 2). The high intake of pine coincided with a relatively high intake of Southern waxmyrtle, both of which are considered non-preferred species (Lay 1967).

Grasses and sedges made up at **least** 17% **of** the winter rumen samples. Fungi, fruit, and dry leaves ware also well represented on both sites. All 4 of these major food categories made up the highest percent by volume in the winter season (Table 3). The small amounts of green **leaves** present in the winter rumen samples indicated the low availability of this forage class during the winter season.

Table 3. Average percent volume of major food categories in **rumens** of 24 deer, by season and study sites.

Major food categories	Winter	Spring	Summer	**Fall** 1/
	-----------	percent	----------	
Site I				
Green leaves	41.2	62.1	62.2	48.8
Dead leaves	6.1	0.2	-	0.7
Stems and buds	8.8	30.5	33.5	17.4
Grasses and sedges	22.2	4.5	1.2	0.9
Fruit	18.2	0.3	3.2	29.4
Mushrooms	3.5	2.5	-	2.8
Site II				
Green leaves	48.9	69.4	67.2	48.5
Dead leaves	3.6	0.3	1.1	0.5
Stems and buds	15.2	26.6	24.8	22.6
Grasses and sedges	17.7	3.7	2.1	9.2
Fruit	0.6	-	0.4	5.1
Mushrooms	14.1	0.2	4.4	13.5

1/ Fall values based on analyses of 2 of the Fall **rumen** samples collected for each study site.

Spring Season

Rumen analysis of spring **rumen** samples showed a marked difference between winter and spring diets. The amount of pine needles in **rumen** samples decreased considerably (Fig. 1). Pine was found in 4 of the 6 **rumen** sampled during the spring season. **On** Site I, 2 of the 3 deer consumed pine for an aggregate volume of **1.9%,** ranking pine eleventh of the sixteen food items identified in the **rumen** samples. All 16 food items exceeded an aggregate volume of 1.0%. Two of the 3 deer from Site II consumed pine **for** an aggregate volume of 1.2%. Twenty-three items were identified from the 3 rumensamples from Site II, 20 of which exceeded 1.0% aggregate volume and accounted for 98% of identifiable food items.

The decrease of pine in spring **rumen** samples coincided with a definite increase in green leaves such as American beautyberry and greenbriar. Southern waxmyrtle was absent from spring **rumen** samples, while species that are leafless in the winter and become available to deer in the spring occurred in the **rumen** samples in relatively large amounts. Foods selected in greatest amounts by deer on both sites were the leaves of American beautyberry, grape and water oak. Deer from Site I also consumed an excess of 3.0% aggregate volume of the leaves of saw greenbriar, Oxalis spp., blueberry, common greenbriar, and **sweetgum** (Table 1).

On Site II, over 3.0% aggregate volume of the leaves of sweetgum, common greenbriar, Carolina buckthorn, Japanese honeysuckle and **blackgum** were consumed (Table 2).

Less than 1.0% by volume of dead leaves and fruit occurred in the spring rumen samples. Grasses and sedges were also very low this season, as were mushrooms. Green leaves comprised at least 62%, and stems and buds made up at least 25% in the spring rumen samples (Table 3). Overall, the amount of grasses and sedges, dead leaves, fruit, and mushrooms in rumen samples decreased considerably in the spring while the amount of green leaves and stems and buds showed a marked increase.

Summer Season

Very little pine was consumed during the summer. Pine was absent from the Site I rumen samples, and occurred in 2 of the 3 rumen samples from Site II for an aggregate volume of only 1.0% (Fig. 1).

Twelve items were identified from Site I rumen samples, seven of which exceeded a 1.0% aggregate volume. These accounted for 96% of identifiable food items. On Site II, 18 items were identifiable from the 3 rumen samples, 12 of which exceeded 1.0% and made up 96% of the identifiable food items.

Overall, summer rumen samples indicated a trend in the deer diet similar to that shown in spring samples. Very little pine was consumed by the deer (Fig. 1). However, a relatively large amount of green leaves of preferred species such as Japanese honeysuckle, greenbriar and American beautyberry was present in the rumen samples. Food selected in greatest amounts on both sites were the leaves of common greenbriar. Deer from Site I selected over 3.0% aggregate volume of the leaves of blackberry, grape, American beautyberry and the fruit of Malus spp. (Table 1). On Site II, deer selected over 3.0% of the leaves of yellow jessamine (Table 2).

Green leaves comprised at least 62% by volume of major food categories, while stems and buds made up at least 24%. Over 1.0% dead leaves were consumed by deer from Site II in the summer, while no dead leaves were found in Site I rumen samples. Very little fruit was found in Site I rumen samples. The opposite was true for mushrooms. Grasses and sedges made up less than 3.0% on both sites in the summer (Table 3).

In general, the percentages of green leaves and stems and buds in summer samples were comparable to spring rumen samples, while dead leaves, mushrooms and grasses and sedges occurred in very small amounts. The amount of fruit in the diet did increase in the summer over spring samples, but did not reach the high percentage of fruit occurring in the diet in winter samples.

Fall Season

Analysis of four of the six rumen samples collected for the fall season was completed. Very little pine was consumed during the fall, Pine was absent from Site I rumen samples and occurred in trace amount in one of the rumen samples from Site II (Fig 1).

Sixteen plant species occurred in rumen samples from Site I, 8 of which exceeded 1.0% aggregate volume. Those 8 items made up 94% of the identifiable food items. On Site II, 15 food items were identified from rumen samples, 11 of which exceeded 1.0% and made up 97% of foods eaten.

The trend established by spring and summer rumen samples continued in the fall samples. The small amount of pine in rumen samples and the large number of species identified in the samples indicated there is still enough green forage available to sustain the deer population. Foods selected in greatest amounts on both sites were the leaves of American beautyberry and oak mast. Species consumed in excess of 1.0% aggregate volume on both sites were the leaves of grape, blackberry, and yellow jessamine. Two-thirds of the deer diet from Site I was made up of acorns and nightshade fruit. Another species consumed in excess of 1.0% on Site I was common greenbriar (Table 1). The fruit and leaves of flowering dogwood and oak mast made up over one-third of the diet of deer from Site II. Other species eaten in excess of 1.0% by volume on Site II were saw greenbriar, Japanese honeysuckle and yaupon (Table 2).

Green leaves comprised at least 48% by volume of major food categories, while stems and buds comprised at least 17% on both sites. Dead leaves made up less than 1.0% by volume on both sites. Grass was less than 1.0% on Site I, but made up 9.2% of the diet on Site II. Fruit ranked highest this season with 29.4% by volume on Site I and 5.6% on Site II. Mushrooms ranked high also with 2.8% on Site I and 13.5% on Site II, but did not make up as high a percentage of the diet as mushrooms did in the winter (Table 3).

Forage Production

The growth of grasses, forbs, and browse was appreciably greater on the windrows in comparison with the areas between windrows. This was expected, due to the rich topsoil pushed into the windrows and the concentration of nutrients from burning of debris in the windrows.

Herbage

A comparisonof dominance, expressed as net dry-matter production, among major plant classes is given in Table 4. Grasses dominated the herbaceous community on both sites, with the net primary production of grasses being much higher on Site II with 181.4 lbs/ac, than on Site I with 92.0 lbs/ac. Forb production was higher on Site I, with 73.1 lbs/ac being produced, than on Site II where 50.4 lbs/ac were produced.

Browse

Browse, which consists of the current leaves and stems of tree, shrubs and woody vines comprised 20.2 lbs/ac or 11% of the total forage on Site I and 20.4 lbs/ac or 8% of total forage on Site II. Woody species preferred by deer comprised a much higher percent of the total dry-matter yield of browse on Site I than on Site II (Table 5). Site I produced 62% preferred browse, while Site II produced only 37%. Dominant species of browse on Site I and Site II are listed in Table 6. Loblolly pine made up at least 17% of the total browse on Site I and 14% on Site II (Table 6).

Table 4. Net primary production of vegetation during 1982 in pounds dry-matter/acre.

Vegetation class	Net Primary Production Site I	Site II
	----lbs/ac----	
Ierbaceous vegetation		
Grasses and grass-like plants	92.0	181.4
Forbs	73.1	50.4
Total herbaoeous	165.1	231.8
Woody vegetation		
Vines	5.2	1.6
Shrubs and tree re-production	1 5	18.8 0
Total woody	20.2	20.4
Total production	185.3	252.2

Table 5. Leaf and stem dry-matter produced[a] in 1982 by preferred and non-preferred species of deer browse (pounds/acre).

	Primary Production Site I	Site II
	-----------lbs/ac-------	
Preferred species		
Leaves	7.1	3.9
Stems	3.0	1.7
Total	10.1	5.6
Non-preferred species		
Leaves	4.3	6.3
Stems	1.9	2.8
Total	6.2	9.3

[a]Dry-matter production of individual plant parts were estimated (70% leaves: 30% stems) using results of forage studies by Blair and Feduccia 1977 and Blair and Brunett 1977.

Table 6. Average percent composition per acre of major browse species on Site I and Site II.

Browse species	Average percent composition per acre Site I	Site II
Callicarpa americana	29.0	18.5
Liquidambar styraciflua	5.0	12.0
Pinus taeda	20.0	16.0
Rubus spp.	18.0	6.0
Quercus falcata	5.0	1.0
Quercus nigra	3.0	1.0
Smilax bona-nox	4.0	2.0
Smilax rotundifolia	4.0	0.5
Smilax glauca	2.0	
Vaccinium spp.	1.5	6.0
Myrica cerifera	1.0	4.0
Ampelopsis arborea	0.5	10.0
Passiflora lutea	4.0	
Sassafras albidum	1.5	
Rhub *copallina*	1.0	0.2
Vitis spp.	1.0	0.1
Nyssa b *ylvatica*	0.5	0.3
Ilex vomitoria	0.3	1.5
Quercus stellata	0.2	1.0
Quercus phellos	0.5	0.1
Gelsemium sempervirens	0.5	0.1
Crataegus spp.	0.5	0.5
Ilex opaca	0.5	0.1
Parthenocissus quinquefolia	0.1	0.1
Ulmus spp.	0.5	0.5
Carya tomentosa		0.5
Acer rubrum	0.1	
Platanus occidentalis	0.5	
Baccharis halimifolia	1.0	

Analysis of variance of the volume of pine in rumen samples showed highly significant ($P < 0.01$) differences between seasons and between study sites. The volume of pine was considerably higher in winter rumen samples, while spring and summer rumen samples contained very small amounts of pine. This seasonal difference was further illustrated by the aggregate volume values calculated for loblolly pine (Tables 1, 2).

A significant block x treatment interaction term indicated that rumen samples collected from one study site during a particular season differed between sites in the volume of pine in rumen samples. Site I generally showed a lower volume of pine in the rumen samples, which indicated that more highly preferred species were present or more abundant on Site I, or that the competition by deer on Site II was more intense than on Site I.

Statistical analysis results may be changed slightly when analysis of variance is performed after results from fall rumen analysis is included. However, the drastic seasonal differences in aggregate volume values for pine indicate differences between seasons and between study sites will remain significant.

SUMMARY AND CONCLUSIONS

Utilization of individual plant species by deer varied between seasons. Foods ranking high in winter were the leaves of loblolly pine, southern waxmyrtle, yellow jessamine and Japanese honeysuckle, and the fruit of night shade, while the leaves of American beautyberry, grape, water oak and greenbriar were favored in spring. In summer, the leaves of blackberry, grape and American beautyberry ranked highest, while oak mast, nightshade fruit and the fruit and leaves of flowering dogwood ranked highest in fall. Differences in deer use of major plant categories followed these trends: green leaves ranked higher than other categories in spring and summer, while fruit and mushrooms made up a substantial part of the deer diet in fall and winter.

Changes in plant species and plant part intake were attributed partly to increasing availability of other more preferred species, or plants may have developed certain physical or chemical properties making them unpalatable to deer during certain times of the year. Longhurst et al. (1968) suggested that biogenesis of inhibitory compounds in maturing vegetation can affect palatability.

Forage production results indicated a difference between study sites in production of grasses and forbs. Total production for Site II was higher due to almost twice as many pounds per acre of grasses produced on Site II, though forb production was less on Site II than on Site I (Table 4). Leaf and stem dry-matter produced by preferred species was much higher on Site I than on Site II, while production of non-preferred species was higher on Site II than on Site 1 (Table 5). These results indicated browse conditions for deer were better on Site I than on Site II, which could partly account for the much higher consumption of pine during the winter on Site II.

Forage production results also determined plant species occurring in rumen samples but not found in the plantations included flowering dogwood, oak mast, and Alabama supplejack.

Winter rumen samples indicated a lower availability of preferred browse with an increased consumption of undesirables such as pine and southern waxmyrtle. Southern waxmyrtle is a widely distributed, evergreen third choice species which is an excellent indicator of the status of deer herds. More than 5 to 10% use in winter indicates heavy pressure on the available food supply by deer (Lay 1967). Lay found when half of the current growth of waxmyrtle is used, pine browsing by deer will follow.

There is little reported.evidence of damage to loblolly pine seedlings due to deer browsing. The digestibility of pine is believed to be governed to some extent by the adverse impact of resins and and volatile oils on the microbial population inhabiting the deer rumen (Nagy 1970).

Southern pines demonstrate a tremendous ability to survive and recover rapidly with resilience from extreme forms and intensities of injury (Lewis 1980). However, if seedlings are in a low state of vigor, under extreme stress, or subjected to extreme temperatures they could be much more vulnerable to injury. This study indicated times of food shortage and low availability of preferred deer browse occurred in January and February. Heavy deer densities could lead to pine damage at this time of the year especially if the seedlings had just been planted.

There is a wildlife management implication in this study which may apply to areas intensively managed for pine pulpwood and sawtimber in the South. As shown by the results of this study, the availability of food resources in pure pine stands of certain ages and at certain times of the year may be seriously limited. Keeping the deer herd at a level in compliance with the amount of food available should be an important consideration to those interested in maintaining a healthy deer herd. When deer are forced to browse loblolly pine, deer suffer as well as the pines.

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APPENDIX

Table 1: The common and scientific names of plants mentioned in the text.

Common names	
Alabama supplejack	*Berchemia scandens* (Hill) K. Koch
American beautyberry	*Callicarpa americana* L.
American holly	*Ilex opaca* Ait.
Blackberry	*Rubus* spp.
Blackgum	*Nyssa sylvatica* Marsh
Blueberry	*Vaccinium* spp.
Common greenbriar	*Smilax rotundifolia* L.
Carolina buckthorn	*Rhamnus caroliniana* Walt.
Deciduous holly	*Ilex decidua* Walt.
Flowering dogwood	*Cornus florida* L.
Grape	*Vitis* spp.
Greenbriar	*Smilax* spp.
Loblolly pine	*Pinus taeda* L.
Nightshade	*Solanum* spp.
Nits-and-lice	*Hypericum* spp.
Plantain	*Plantago* spp.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Saw greenbriar	*Smilax bona-nox* L.
Southern waxmyrtle	*Myrica cerifera* L.
Sweetqum	*Liquidambar styraciflua* L.
Water oak	*Quercus nigra* L.
Yaupon	*Ilex vomitoria* Ait.
Yellow jessamine	*Gelsemium sempervirens* (L.) Ait. f.
Sneezeweed	*Helenium flexuosum* Raf.

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